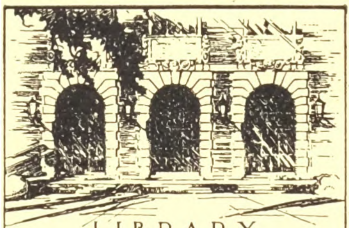
This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

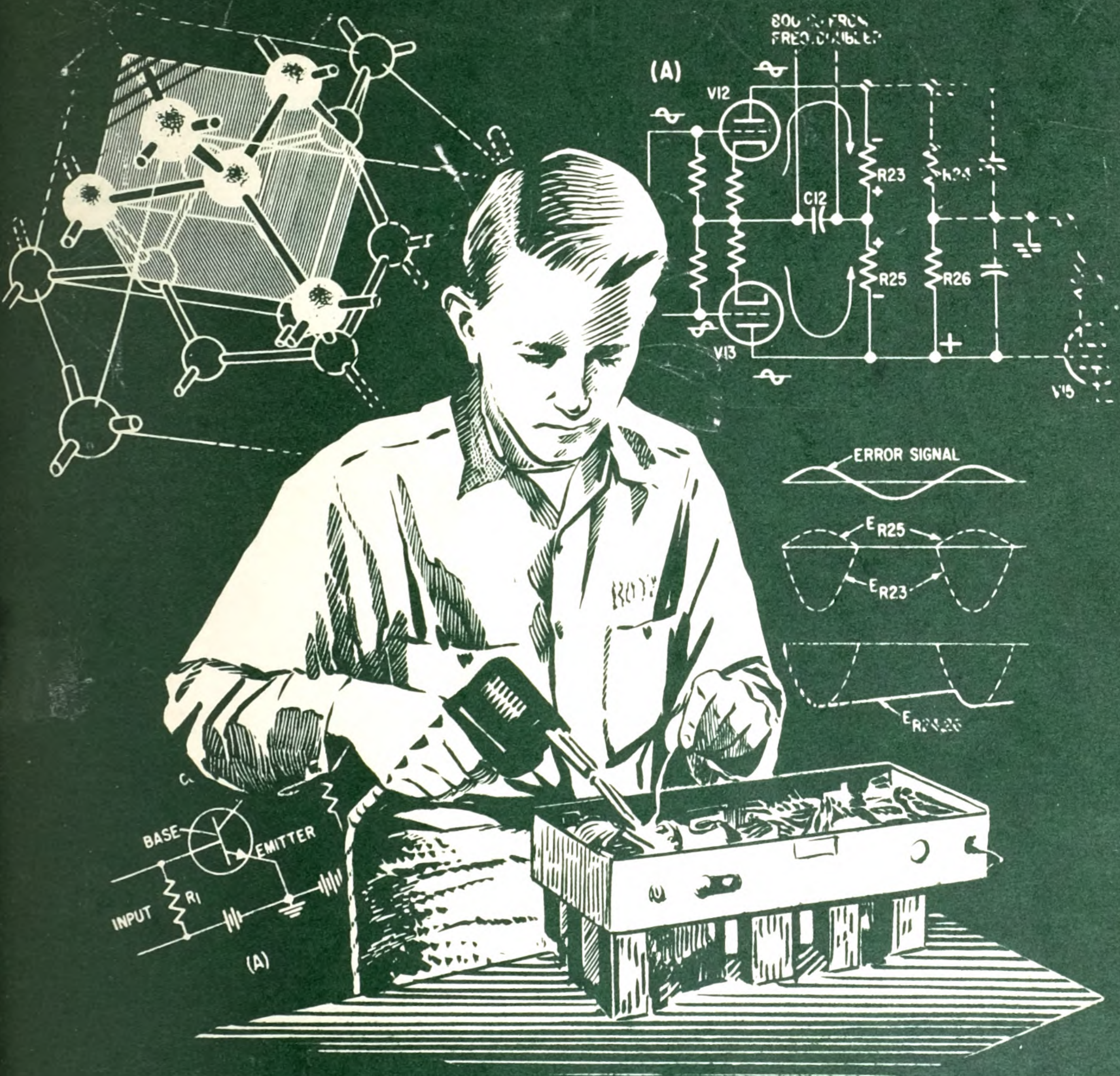
Google™ books

https://books.google.com



LIBRARY
OF THE
UNIVERSITY
OF ILLINOIS

629.1354
Un3ae
1959



AVIATION
ELECTRONICS TECHNICIAN 3 & 2

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10317-A

D208.11: Av5/6/959

AVIATION ELECTRONICS TECHNICIAN
3 & 2

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10317-A

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

ENGINEERING LIBRARY
ALTGELD HALL STORAG

629.1354
Un3ae
1959

PREFACE

This Navy Training Course is one of a series of courses written especially for the enlisted Aviation Electronics Technician. It is intended primarily to furnish useful information to those men of the U. S. Navy or Naval Reserve who are preparing for advancement, especially the AT striker and the AT3. This course may also be used to improve any technician's daily working proficiency.

The *Manual of Qualifications for Advancement in Rating,* NavPers 18068, (Revised), has been used as a guide in writing the training course. These qualifications are included in the back of this course as appendix VI and are current through CHANGE 13 to the manual.

After an introductory chapter, this course continues with a discussion of the safety precautions to be used when performing electronics maintenance. The next chapter presents information that relates to publications, records and reports, and procurement of equipment. Chapter 4 discusses the fundamentals of transistors and magnetic amplifiers, and chapter 5 is an introduction to computers. Aircraft electric power systems are discussed in chapter 6. General maintenance procedures along with a description of frequently used test equipments are covered in chapters 7 and 8. The next four chapters deal with airborne communication equipment, navigation equipment, and radar equipment. Chapter 13 discusses electronic countermeasures, both active and passive. The last two chapters are concerned with (1) magnetic airborne detection equipment, and (2) sonobuoys and airborne sonor.

Basic Electricity, NavPers 10086 (current edition) and *Basic Electronics,* NavPers 10087 (current edition) contain essential background information for the AT rating. Before you begin work on this training course you should be familiar with the contents of these basic courses.

This training course, *Aviation Electronics Technician 3 & 2,* has been prepared by the United States Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit is also given to the Aviation Electronics Technician School, Memphis, Tennessee, for preparation of the end-of-chapter questions.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.
	12	9 mos.	15 mos.	21 mos.	24 mos.	36 mos.	42 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.
DRILLS ATTENDED IN GRADE#	48	27	27	45	54	72	108
	24	16	16	27	32	42	65
	12	8	13	19	21	32	38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48	14 days	14 days	14 days	14 days	28 days	42 days
	12	14 days	14 days	14 days	28 days	42 days	42 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days
PERFORMANCE TESTS		▨	▨	Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A	E7 to E8	E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, HM3, DT3, PT3.			Class B for AGCA, MUCA.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.				Special evaluation required.	
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.				Service-wide and selection board.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.						
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS are advanced to fill vacancies and must be approved by CNARESTRA.							

*All advancements require commanding officer's recommendation.

READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086 (current edition)
Basic Electronics, NavPers 10087 (current edition)
Mathematics, Vol. 1, NavPers 10069-B
Mathematics, Vol. 2, NavPers 10070-A
Basic Hand Tool Skills, NavPers 10085
Basic Machines, NavPers 10624
Standard First Aid Training Course, NavPers 10081

USAFI TEXTS

The United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Number	Title
B 150	*Review Arithmetic*
C 164	*Beginning Algebra I*
C 165	*Beginning Algebra II*
C 290	*Physics I*
C 291	*Physics II*
B 781	*Fundamentals of Electricity*
B 885	*Fundamentals of Radio*
A 887	*Intermediate Radio*

---

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CONTENTS

Chapter Page

1. The Aviation Electronics Technician 1
2. Safety precautions in electronics maintenance 8
3. Publications, records and reports, procurement of equipment 17
4. Transistors and magnetic amplifiers 32
5. Fundamentals of computers 67
6. Aircraft electric power systems 103
7. Electronic test equipment 133
8. Aircraft electronics maintenance 183
9. Airborne communication equipment 219
10. Airborne communication equipment—Continued 254
11. Airborne electronic navigation equipment 292
12. Airborne radar 339
13. Electronic countermeasures 371
14. Magnetic airborne detection equipment 388
15. Airborne sonar and sonobuoys 403

Appendix

I. Electronics and electrical terms 427
II. Greek alphabet 432
III. Formulas 433
IV. Laws of exponents 436
V. Answers to quizzes 437
VI. Qualifications for advancement in rating 441

Index 459

STUDY GUIDE

The following table indicates which chapters of this training course apply to your rating. To determine the sections of this course that you should study, use the following procedure:

1. Select the column that applies to your rating. If you are advancing in the General Service Rating, you will use the column headed "AT". If you are advancing in one of the Emergency Service Ratings, you will use one of the columns headed "ATR," "ATS," or "ATN."

2. To the right of each chapter number appear rating level designations, each designation falling under a particular rating heading (AT, ATR, ATS, ATN). WHEN THE RATE FOR WHICH YOU ARE PREPARING TO ADVANCE appears to the right of a given chapter, you should study that chapter.

3. These chapters contain information which will assist you in meeting the qualifications for your rating. In order to gain a well-rounded view of the duties of the General Service Rating, it is recommended that you read the other chapters of this course even though they do not pertain directly to your rating.

Chapter	AT	ATR	ATS	ATN
1	3, 2	3, 2	3, 2	3, 2
2	3, 2	3, 2	3, 2	3, 2
3	3, 2	3, 2	3, 2	3, 2
4	3, 2	3, 2	3, 2	3, 2
5	3, 2	3, 2	3, 2	3, 2
6	3, 2	3, 2	3, 2	3, 2
7	3, 2	3, 2	3, 2	3, 2
8	3, 2	3, 2	3, 2	3, 2
9	3, 2	---	---	3, 2
10	3, 2	3, 2*	3, 2*	3, 2
11	3, 2	3, 2*	3, 2*	3, 2
12	3, 2	3, 2	---	---
13	3, 2	---	3, 2	---
14	3, 2	---	3, 2	---
15	3, 2	---	3, 2	---

*NOTE: The ATR's and ATS's are required to study only the sections of chapter 10 that relate to tape recorders and television, and the section of chapter 11 that relates to infrared.

AVIATION ELECTRONICS
TECHNICIAN
3 & 2

CHAPTER 1

THE AVIATION ELECTRONICS TECHNICIAN

As a member of the air arm of the United States Navy, you belong to one of the greatest teams in the world. As an Aviation Electronics Technician Striker or AT3, you have one of the most important jobs on this team. You are a specialist among many specialists who must all work together to have an efficient organization.

In peacetime or wartime, you, as an Aviation Electronics Technician, must be able to maintain and operate many complex pieces of aviation electronic equipment.

This training course is written to help you advance in rating. By enabling you to become better trained, the course will also help the Navy to fulfill its mission.

Before studying this course, read the introductory pages if you have not already done so. Give special attention to the PREFACE and STUDY GUIDE.

Duties and Responsibilities of the AT 3 & 2

MILITARY

No matter what a petty officer's technical specialty may be, he should know and understand general and military subjects. He should be able to take charge of a group of men and show and tell them how a job should be done. A petty officer should know what to do and how to do it when faced with matters of first aid, hygiene, damage control, fire prevention, and atomic, biological, and chemical warfare. In short, he must be a leader whose responsibilities are to accomplish his military duties and take care of his men.

One of the main responsibilities of a leader, and therefore a petty officer, is to instruct others. As you climb the rating ladder, you will find that more men will look to you for instruction.

A petty officer's working relationship with others is of great importance to the success of his work and the mission of his activity. In your day-to-day working relationships, you will be required to cooperate with others. This is not only true within your own division but with men in other divisions. Being able to get along is, at times, just as necessary as proficiency in performing technical skills.

The ability to get along with others is within itself a definite skill. This skill can be developed in much the same manner as a technical skill; that is, the many different skills you must possess may each be studied and developed. Some of these are the understanding of another man's job, his problems, and his abilities. You must possess skill in teaching, leading, and in some cases inspiring the men with whom you work and for whom you are largely responsible. Detailed information to help you develop these skills is given in the training courses *Basic Military Requirements*, NavPers 10054, and *Military Requirements for Petty Officer 3 & 2,* NavPers 10056. You should be familiar with the entire contents of both training courses prior to taking the exam for advancement in rating. In order to get the most out of this course that you are just beginning (*AT 3 & 2*, NavPers 10317-A), you should first study chapter 21 of *Basic Military Requirements* and chapters 1, 2, 3, and 14 of *Military Requirements for Petty Officer 3 & 2.*

PROFESSIONAL

As a petty officer 3rd or 2nd class, your professional duties will vary slightly, depending upon the activity to which you are assigned. In some activities your job will deal solely with the maintenance of airborne electronic equipment. Yet in other activities you will perform your duties by inflight operation and maintenance of this equipment. You will install, remove, troubleshoot, and maintain airborne electronic equipment of many different types. This will include associated test equipment.

Types and Locations of Billets

As an Aviation Electronics Technician, you are most likely to be assigned to an operating squadron, a supporting activity, an air station, or the aviation maintenance division of an aircraft carrier or seaplane tender. AT's may also be assigned to a training activity as an instructor or to a facility engaged in testing and evaluating electronic equipment.

In order that you will understand the nature of the maintenance at these various activities, the definitions of the different types of maintenance, as defined by the Chief of Naval Operations, are given.

Line maintenance is the preparation of aircraft for flight. This includes, but is not limited to, preflight and daily inspections, adjustment, servicing, correction of minor discrepancies, and troubleshooting.

Hangar maintenance is the routine upkeep of aircraft. It includes, but is not limited to, accomplishment of periodic and special inspections, replacement of components and accessories, incorporation of specified changes, and performance of work as prescribed by bulletins.

The final definition, shop maintenance, is the specialized maintenance required for aircraft which is beyond the scope of line or hangar maintenance. It is normally the highest level of maintenance performed by the operating forces. It includes, but is not limited to, bench check, test, calibration, modification, and repair of accessories and components; repair of aircraft; manufacture of certain parts; machine work; incorporation of specified changes; and performance of work as prescribed by bulletins.

SQUADRON

The aircraft squadron, which is the standard operating unit in naval aviation, is composed of a number of assigned aircraft. The total number of aircraft is dependent upon the mission of the squadron. The squadron also contains the necessary personnel for its operation, maintenance, and minor repairs. The number of maintenance personnel will depend to a large degree upon the type of squadron (supported or self-supported) and the type of aircraft.

There are two general types of squadrons. The first is the supported squadron. This is the squadron which performs line and hang maintenance on its assigned aircraft. Th squadron also performs shop maintenance utilizing facilities provided by the supporti activity.

The second general type is the sel supporting squadron, which usually perfor special missions. Included in a list of sel supported squadrons are Airborne Ear Warning squadrons and Composite squadron This type of squadron (self-supporting) co sists of aircraft, flight crews, maintenan personnel, material, and equipment sufficie to perform routine upkeep and servicing assigned aircraft. NOTE: One of the ma differences between supported and sel supported squadrons is the use of faciliti provided by the supporting activity.

A group of squadrons, comprising bo fighter and attack, intended to operate as unit aboard a carrier is known as a Carri Air Group (CVG). A group of patrol squadro under one tactical commander is known as Fleet Air Wing (FAIRWING).

Because his duties will be mostly maint nance of aviation electronic equipment, t Aviation Electronics Technician will usual be part of the maintenance department wit the squadron. Other departments in the usu squadron are: administration, operation material, and gunnery (or ordnance).

NAVAL AIR STATIONS

Another billet that exists for an Aviati Electronics Technician is at a naval air st tion. One possible assignment is to the en neering branch of the operations departm where you will perform the maintenance fun tions of your rate. Some air stations have Overhaul and Repair (O&R) Department. T department has an aviation electronics rep section where AT's perform overhaul major repair work on all types of aviat electronic equipment.

A recent change in naval aviation main nance decommissioned Fleet Air Serv Squadrons (FASRon's) and assigned their dut to the naval air stations. The FASRon was unit that supported the squadrons in all logis requirements ashore except berthing and messing. These duties will now be performed by the NAS to which the squadron is attached. Ships will, of course, continue to be the supporting activity for squadrons embarked.

AT's formerly assigned to duty at FASRon's will continue to support the squadrons, but will be assigned to NAS. They will be required to operate, inspect, test, and repair electronic equipment assigned to the supporting activity to which they are attached and the squadrons that their activity supports. They will also be required to incorporate service changes as appropriate. Authorized repairs and adjustment of test equipment used for support of squadrons will also be required.

AIRCRAFT CARRIERS AND SEAPLANE TENDERS

Aircraft carriers and seaplane tenders are organized into the following departments: operations, navigation, gunnery (or deck), engineering, supply, medical, dental, and air. The air department is divided into divisions, one of which is the aircraft maintenance division. Aboard the typical carrier or tender, the Aviation Electronics Technician is assigned to the aircraft maintenance division. Generally the maintenance division afloat provides the same service to embarked squadrons as does the supporting activity ashore.

TRAINING BILLETS

In training billets, AT petty officers serve as instructors in the Aviation Electronics Technical Training Schools. These instructors are carefully chosen since it is important that they be well qualified in the knowledge of their subject and possess teaching ability. They conduct classes in many of the phases of electronics theory and practice, including such subjects as fundamentals of electricity and electronics, communication and navigation equipment, and radar systems. They instruct trainees in the authorized procedures for making operational and maintenance tests of the aircraft electronic equipment, and in the functions and operation of standard and specialized test equipment.

TEST CENTERS AND DEVELOPMENT SQUADRONS

Aviation Electronics Technicians are assigned to Naval Test Centers and development squadrons to assist in the work of testing and evaluating new aircraft electronic equipment. These units assist in determining the suitability of new equipment for introduction into the fleet. They also work out procedures for training personnel in the use of the equipment and in rendering many other services to various naval activities in equipment test and development.

Scope and Purpose of This Training Course

The purpose of this training course is to aid the striker in his advancement to 3rd class petty officer and the 3rd class petty officer in his advancement to 2nd class petty officer. It may also serve as a reference source for the other AT rates.

This course presents information that is peculiar to aircraft electronic equipment. In order for you to make satisfactory progress you must possess a sound technical background. That is why it is a good idea to stop at this point and take inventory of the things you DO NOT KNOW.

You will find that appendix VI of this training course will be of much use in taking stock of the gaps in your technical knowledge. This appendix lists the AT practical factors and examination subjects contained in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised), through change 13. You should be thoroughly familiar with these before preparing for advancement. This knowledge will also prove helpful when it is time to take your examination. The lists will serve as a study guide and help you determine subjects on which you need further instruction.

If your inventory of the things you do not know reveals that you need more basic study, you will need to obtain other books. The most useful books for this purpose are the *Basic Navy Training Courses*. These are the "blue covered" training courses which serve three purposes: they give you the background you will need to prepare for a technical rating; they offer a handy refresher course in subjects you may have forgotten; and they are useful throughout all your Navy experience as a handy reference library.

A listing of some of these basic courses with a brief summary of their content is as follows:

Mathematics, Vol. 1, NavPers 10069-B, begins with a general statement of the basic principles of mathematics. It goes on to present information on negative numbers, common fractions, decimals, exponents, radicals, common logarithms, and the slide rule. The course also presents various fundamentals of algebra, such as linear equations in 1 and 2 variables, quadratic equations in 1 variable, formulas, and imaginary numbers.

Basic Machines, NavPers 10624, presents background information for working with simple machines. It covers such things as work, power, and force as applied to actual Navy gear. It starts from simple illustrations and finally works into a discussion of electric, hydrostatic, hydraulic, and mechanical machines. This course will enable you to build a sturdy foundation for future study and practical work.

Basic Hand Tool Skills, NavPers 10085, presents in a concise form descriptions of the basic handtool operations. It contains information on layout, testing, checking, setting, and cutting. For the most part, only handtools are covered; a few illustrations of power equipment are included.

Blueprint Reading and Sketching, NavPers 10077-A, begins with a general discussion of the uses and kinds of blueprints. The text explains the language of a blueprint—lines, sections, symbols, dimensions, conventions, notes, and titles. Layout tools and geometry required, as well as procedures involved, are discussed. It concludes with sections on wiring and schematic diagrams.

Basic Electricity, NavPers 10086, is intended as a basic reference for all enlisted personnel of the Navy whose duties require them to have a knowledge of the fundamentals of electricity. Like the other courses, it starts from very basic things by introducing a broad picture of the electrical characteristics of matter and proceeds with a discussion of static electricity, electricity in motion, and electrical circuits. It explains the uses of Ohm's law and the power equations, and makes applications to actual circuits. Emphasis is placed on the various types of circuits—series, parallel, and series-parallel—and on the theory of induction as applied to electrical motors and other electrical apparatus. The essentials of generators and motors are explained. The closing chapters include a basic treatment of transformers, synchro units, and electrical measuring instruments.

Basic Electronics, NavPers 10087, is intended as a basic reference for all enlisted personnel of the Navy whose duties require them to have a knowledge of the fundamentals of electronics. The AT striker in his preparation for advancement should be familiar with chapters 2, 3, 4, 5, 7, 8, 9, 12, 13, and appendix II. The AT3 in his preparation for AT2 should be familiar with the entire book.

The first few chapters are concerned with the operating principles of electron tubes and their application in electronic circuits; power supplies are also covered. Communications equipment is covered under the chapter headings "Transmitters," "Transmission Lines," "Antennas and Propagation," and "Elementary Communication Receivers." One chapter is devoted to electronic test equipment; the last chapter is an introduction to radar.

There are other sources of information that will prove helpful to you and many of these are briefly discussed in chapter 3 of this course under the heading "Publications, Records and Reports, and Procurement of Equipment."

Navy Training Courses may be obtained through your education officer or from the Information and Education (I & E) office. The publications discussed in chapter 3 will normally be found in your shop or technical library.

Remember, one of the most important tools of learning is the ability to know HOW and WHERE to find INFORMATION.

This particular training course, *AT 3 & 2*, NavPers 10317-A, contains information covering the qualifications for advancement to AT3 or AT2. Refer to appendix VI to determine specifically what subject matter you should understand prior to taking your advancement examination. This course is concerned primarily with airborne electronic equipment, such as communications equipment, navigation equipment, radar equipment and associated test equipment. For a description of what is covered refer to the table of contents.

Qualifications for Advancement

The *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), is of vital interest to the division officer and the enlisted man alike. This publication is the official manual which promulgates the minimum qualifications for the advancement in rating of enlisted personnel in the regular Navy and the Naval Reserve. It covers in more or less broad terms both the military and the professional requirements for advancement in all ratings in the Navy. The Bureau of Naval Personnel issues CHANGES to the quals manual in order to keep the requirements of your rating up to date. The qualifications printed in appendix VI of this training course for the AT rating are current through change 13 only. It is important that you refer to the latest change to the quals manual when preparing for any advancement examination. This is the only way you can be certain that you are studying all of the requirements of your rating. Visit your information and education office or consult your education and training officer for information concerning the latest changes to the manual.

The naval rating structure is subject to continual review to insure the most effective manpower utilization and career patterns. Beginning with change 12, two different and distinct rating structures exist in the *Qualifications Manual* (NavPers 18068). These are the structures established in 1947 and a new structure established in 1957. The older structure will be replaced by the new structure on an evolutionary basis with ratings revised in terms of the new structure as rapidly as possible. At the time this training course is published, the AT rating is still operating under the structure established in 1947. It is suggested that you study the preface of the quals manual since it sets forth in detail the aspects of the two structures. The AM rating has already been changed to the new structure; it is suggested that you compare the AT and AM ratings as a means of better understanding the new structure. Following is a brief description of the two structures.

The 1947 structure provides for General Service Ratings and Emergency Service Ratings. Presently there are three Emergency Service Ratings: Aviation Electronics Technicians R (Radar), Aviation Electronics Technicians S (ASW), and Aviation Electronics Technicians N (Communication and Navigation Equipment). The qualifications for advancement in these three ratings are given in appendix VI. This appendix also contains the qualifications for the General Service Rating (AT) which is the type of rating normally held by Regular Navy personnel in peacetime. The Emergency Service Rating is the type of rating held by most members of the Naval Reserve and to which Regular Navy personnel would be shifted in wartime as directed by the Chief of Naval Personnel.

The requirements for advancement in the Emergency Service Ratings and the Selective Emergency Service Rates programs are the same. Regular Navy personnel and Naval Reserve personnel striking for 3rd class petty officer must strike for either ATR3, ATS3, or ATN3. Reserve personnel striking for 2nd class petty officer and above will continue in the Emergency Service Rating. Regular Navy personnel striking for 2nd class and above will continue in the General Service Rating. Refer to the study guide in the front of this course for a listing of the chapters that should be studied in preparing for your particular advancement.

In recent years the rapid introduction of complex technological developments in the Navy, as well as greater use of noncareer personnel, has produced a need for modifications to the 1947 structure. A structure is needed which will provide for specialization and reduce training time. The concept of the broadly trained and qualified petty officer is retained in the new structure and, at the same time, effective manpower utilization is insured by providing desirable specialization in the lower pay grades of certain ratings. Also, this new structure applies equally to both the regular Navy and the Naval Reserve and there is no change in an enlisted man's rating in the case of mobilization. The new structure consists of (1) general ratings, (2) service ratings, and (3) emergency ratings.

A GENERAL RATING reflects qualifications in all aspects of an occupational field and insures broadly qualified senior petty officers. It is similar to and will replace the present general service rating and is applicable to both the regular Navy and the Naval Reserve. A SERVICE RATING reflects qualifications in some of the aspects of an occupational field and provides specialization where deemed desirable. It is similar to and replaces the emergency service ratings for the Naval Reserve and also it is applicable to the regular Navy. An EMERGENCY RATING reflects qualification in a civilian skill which is not identified in the peacetime Navy but is required to be identified in wartime. It is similar to and will replace the exclusive emergency service rating.

In summary, the new rating structure will provide (1) a completely integrated system applicable to both peacetime and wartime, which undergoes no basic change in structure during mobilization, and (2) a structure with inherent incentives to provide necessary generalization at the senior pay grades and built-in flexibility to accommodate specialization in the lower pay grades where necessary.

PRACTICAL FACTORS

Practical factors are those abilities that you must be able to perform prior to your advancement. These are given in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). They are also included in appendix VI of this training course. The requirements listed under practical factors include the minimum skills and abilities that you should possess in order to advance. You can best learn how to fulfill these requirements by closely observing the work of experienced AT's and by continued practice on the part of yourself. Make it your business to actually perform each of the practical factors required of you for advancement.

Closely associated with the practical factor section of the qualifications is the *Record of Practical Factors*, NavPers 760 (AT). This form includes a list of both the military and professional practical factors for which you are responsible. Instructions for completing this form are provided at the top of the first page.

Each man studying for advancement in rating should have a copy of this form for his personal record and guidance. A copy of this form is held by the division officer or by the appropriate supervising officer of each man in pay grade E-3 through E-6. Upon transfer of an enlisted man, the supervising officer's copy of the form is signed, inserted in the correspondence side of the service record, and forwarded.

The appropriate items on NavPers Form 760 (AT) must be completed before you are eligible to take the examination for advancement in rating. It is your responsibility to insure that the supervising officer's copy of Form 760 (AT) is appropriately completed.

EXAMINATION SUBJECTS

Manual of Qualifications for Advancement in Rating, NavPers 18068, also includes the minimum knowledges necessary for performance of the practical factors and must be fulfilled by passing a written examination. When reading the items in the examination subject section (appendix VI of the course), the prefix KNOW THE should be understood. For example, item 1 under "Operational" should read as follows: "KNOW THE effects of electrical shock, method of resuscitation of a person unconscious from electrical shock, and treatment for electrical burns."

A bibliography titled *Training Courses and Publications for General Service Ratings*, NavPers 10052, is issued in revised form annually by the Bureau of Naval Personnel. This booklet lists Navy Training Courses and other publications required or recommended for study for the advancement in each of the rates and ratings. This booklet is also applicable to Naval Reservists on inactive duty. It is a bibliography of reference sources from which examination questions for your advancement will be taken. Training courses which are marked by an asterisk must be completed for specific rate levels before you are eligible to take the advancement examination. It must be realized that, as indicated in the *Manual of Qualifications for Advancement in Rating* NavPers 18068, all higher pay grades are held responsible for the materials listed for the lower rates of that particular rating.

QUIZ

1. The Manual of Qualifications for Advancement in Rating, NavPers 18068 (Revised)
    a. is of little value to the individual
    b. is only beneficial to the individual when adopted by the local command
    c. gives the specific requirements, both military and professional, for advancement in rating of all ratings in the Navy
    d. specifies broadly the professional and military requirements for all ratings in the Navy

2. When a striker is preparing for advancement to AT3, he should acquire skill in teaching, leading, and inspiring others. Which of the following training courses would be his greatest help?
    a. NavPers 10069-B
    b. NavPers 10085
    c. NavPers 10054
    d. NavPers 10624

3. When serving aboard a carrier, an AT3 will normally be assigned to the
    a. electronics department
    b. operations department
    c. navigation department
    d. air department

4. This training course will help you advance in rating and enable you to
    a. become a chief petty officer
    b. become better trained
    c. make more money
    d. become a commissioned officer

5. Practical factors
    a. can be best fulfilled by correspondence courses
    b. are set forth by local authority
    c. are those abilities or skills a candidate must demonstrate before he can be advanced to the next higher rate
    d. are completed by observing a qualified man performing the job under actual conditions

6. One of the main responsibilities of a petty officer is to
    a. do better work after becoming rated
    b. give as well as take orders
    c. stand watches
    d. instruct others

7. A rating which requires qualifications in a limited part of an occupational field is known as a/an
    a. limited rating
    b. service rating
    c. general rating
    d. emergency rating

8. As an AT3 assigned to line maintenance, you will be primarily concerned with
    a. adjustment, servicing, incorporation of specified changes, and bench check of accessories
    b. calibration of equipment, repair of test equipment, adjustment, and repair of parts
    c. correction of minor discrepancies, daily and preflight inspections, servicing, and troubleshooting
    d. adjustment, servicing, modifications, incorporation of specified changes, and special inspections

9. The best guide to use in preparing for advancement in rating is
    a. Basic Navy Training Courses
    b. Record of Practical Factors
    c. Manual of Qualifications for Advancement in Rating
    d. Division Officer and Shop Chief

10. The best source of knowledge concerning the fundamentals of electronics can be found in which of the following?
    a. Basic Electricity, NavPers 10086
    b. Manual of Qualifications for Advancement in Rating, NavPers 18068
    c. Record of Practical Factors
    d. Basic Electronics, NavPers 10087

CHAPTER 2

SAFETY PRECAUTIONS IN ELECTRONICS MAINTENANCE

When working with electronic equipment, there is one rule that must be strongly stressed: SAFETY FIRST. Whether you are working in the shop, on the line, or during a flight you should follow prescribed safety procedures. You must be aware of the many dangers that are associated with this type of work. The most common danger that you will encounter is that of the high voltages that are present in most equipment. Also, when working with aircraft, there is the possibility of falling from the aircraft, of being burned by a jet blast, or of being struck by propeller or rotor blades.

The Navy Training Courses *Airman,* NavPers 10307, and *Standard First Aid Training Course,* NavPers 10081, contain much safety information with which you should be familiar. It is recommended that you acquaint or reacquaint yourself with the sections of *Airman* that deal with safety as it relates to naval aviation; specific reference should be made to chapters 8, 9, 10, 11, 12, 16, and 17. The *Standard First Aid Training Course* is designed as a basic reference in the field of first aid and since all naval personnel are required to possess a knowledge of the principles of first aid you should become familiar with this training course.

Safety precautions in this chapter are not intended to replace information given in instruction books or in other applicable instructions for maintenance of electronic equipment. If at any time there is doubt as to what steps and procedures you should follow while working on electronic equipment, consult the leading petty officer.

You should regard the formation of safe and intelligent work habits as being equal in importance to the development of your knowledge of electronic equipment. One of your primary objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions and in avoiding unsafe acts.

Under the heading "Basic Precepts," the *United States Navy Safety Precautions* (OpNav 34P1) makes the following statement:

"Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts."

This publication then gives the following general safety rules which apply to personnel in all types of activities:

"Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

"a. Reporting unsafe conditions. Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

"b. Warning others. Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

"c. Personnel protective equipment. Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performance of his work or duty.

"d. Report of injury or ill health. All personnel shall report to their supervisors any injury or evidence of impaired health occurring in the course of work or duty.

"e. Emergency conditions. In the event of an unforeseen hazardous occurrence, each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

The safety precautions which apply to the work and duty of Aviation Electronics Technicians include those pertaining to work don in and around aircraft, precautions agains electric shock and electric burns, and thos which concern the proper use of handtools an small power tools. In addition to these, it i also necessary that the technician know th authorized methods for dealing with fires c electric origin, for treating burns, and fo giving artificial respiration to persons suffering from electric shock.

SAFETY PRECAUTIONS

Precautions With Regard to Aircraft

In addition to all local orders and directives the following general rules should be observed

Pay strict attention to all warning signs placed in or around any aircraft or in the hangar.

Do not smoke or bring any type of open flame within 50 feet of any parked aircraft. Remember that vapor from aviation fuel can be ignited in a number of ways—by lighted cigarettes, by static discharges, and by sparks from tools or from electrical and electronic equipment. Radio transmitters installed in aircraft should not be operated during fueling of the aircraft, or within 50 feet of any such fueling operation.

Storage batteries should not be disconnected or removed from their circuits within any aircraft immediately after flight without first ventilating the container to allow any gas accumulated during charging to escape. An inspection should be made before removal to insure the opening of all switches, to prevent the possibility of a spark being generated at the terminal of the battery when the connection is broken.

During refueling, radar equipment should not be operated within 75 feet of the plane, and no electrical apparatus supplied by outside power (such as droplights and floodlights) should be operated in or near it.

See that combustible materials such as rags and clean waste are stowed in covered metal containers. Used waste and rags should never be discarded near aircraft but should always be put in plainly marked metal receptacles.

In the air the pilot in command of the aircraft is responsible for the safe and orderly conduct of the flight. When the technician wishes to operate radio or radar transmitters or to make any unusual repairs on the equipment, he must always request permission from the pilot before proceeding.

General Safety Precautions in Electronics Maintenance

Because of the possibility of injury to personnel, the danger of fire, and possible damage to material, all repair and maintenance work on both electronic and electrical equipment should be done ONLY by duly authorized and assigned persons.

When any electronic equipment is to be overhauled or repaired, the main supply switches or cutout switches in each circuit from which power could possibly be fed should be secured in the open position and tagged. The tag should read, "This circuit was ordered open for repairs and shall not be closed except by direct order of . . ." (usually the person directly in charge of the repairs). After the work has been completed, the tag (or tags) should be removed by THE SAME PERSON.

The covers of fuse boxes and junction boxes should be kept securely closed except when work is being done. Safety devices such as interlocks, overload relays, and fuses should never be altered or disconnected except for replacements. Safety or protective devices should never be changed or modified in any way without specific authorization.

Fuses should be removed and replaced only after the circuit has been deenergized. When a fuse blows, it should be replaced only with a fuse of the same current rating. When possible, the circuit should be carefully checked before making the replacement, since the burned-out fuse is often the result of circuit fault.

Electric Detonators

Certain types of electric detonators can be fired by the action of radiofrequency energy. All electric detonators, or igniters, and also electrically fired rocket motors and electric ordnance fuses, should never be exposed or located within five feet of any type of transmitting equipment, including antennas and antenna leads. No danger due to radiofrequency potentials exists, however, with detonators of any type while they are enclosed in covered metal containers.

High-Voltage Precautions

Personnel should never work alone near high-voltage equipment. Tools and equipment containing metal parts, such as brushes and brooms, should not be used in any area within four feet of high-voltage circuits or any electric wiring having exposed surfaces. The handles of all metal tools, such as pliers and cutters, should be covered with rubber insulating tape. (The use of plastic or cambric sleeving or of friction tape alone for this purpose is prohibited.)

Before a worker touches a capacitor which is connected to a deenergized circuit, or which is disconnected entirely, he should short-circuit the terminals to make sure that the capacitor is completely discharged. Grounded shorting prods should be permanently attached to work benches where radar equipment and other types of electronic devices are regularly serviced.

Do not work on any type of electrical apparatus with wet hands or while wearing wet clothing, and do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, technicians should first remove all rings, wristwatches, bracelets, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fastener.

Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

Transmitter adjustments should not be made while the equipment is energized unless the adjustments can be accomplished from the front control panel. Similar precautions should be taken with oscilloscope circuits, which employ voltages corresponding to those used in transmitting equipment.

Energized Circuits

Insofar as is practicable, repair work on energized circuits should NOT be undertaken. When repairs on operating equipment must be made because of emergency conditions, or when such repairs are considered to be essential, the work should be done only by experienced personnel, and if possible, under the supervision of a communications or electronics officer. Every known safety precaution should be carefully observed. Ample light for good illumination should be provided; and the worker should be insulated from the ground with some suitable nonconducting materials such as several layers of dry canvas, dry wood, or a rubber mat of approved construction. The worker should, if possible, use only one hand in accomplishing the necessary repairs. Helpers should be stationed near the main switch or the circuit breaker so that the equipment can be deenergized immediately in case of emergency. A man qualified in first aid for electric shock should stand by during the entire period of the repair.

Volatile Liquids

Volatile liquids such as insulating varnish, lacquer, turpentine, and kerosene are dangerous when used near electronic equipment which is operating because of the danger of igniting the fumes by sparks. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid any accumulation of fumes and that all fumes are cleared before the equipment is energized.

Alcohol should never be used for cleaning. Neither should carbon tetrachloride be employed as a cleaning agent. Unlike alcohol, the use of carbon tetrachloride does not create a fire hazard; but it is dangerous because of the injurious effects of breathing its vapor. The careless use of carbon tetrachloride may resul in headache, dizziness, and nausea. If the fumes are breathed in poorly ventilated compartments, the effect may be loss of consciousness or even death. For these reasons, the use of carbon tetrachloride as a solvent or cleaner has been specifically prohibited in Navy maintenance operations. When cleaning electrical or electronic equipments or parts, always use the approved cleaning agent, Dry Cleaning Solvent, Federal Specification P-S-661.

Electrical Fires

In case of electrical fires, the following steps should be taken:

1. Deenergize the circuit.
2. Call the Fire Department if the fire is i a hangar or a shop.
3. Control or extinguish the fire, using th correct type of fire extinguisher.
4. Report the fire to the appropriate authority.

For combating electrical fires, use a CO (carbon dioxide) fire extinguisher and direct toward the base of the flame. Carbon tetrachloride should never be used for fire fightin since it changes to phosgene (a war gas) upo contact with hot metal, and even in open air thi gas creates a hazardous condition. The application of water to electrical fires is dangerou and foam-type fire extinguishers should not b used since the foam is electrically conductive.

In case of cable fires in which the inne layers of insulation or insulation covered b armor are burning, the only positive method preventing the fire from running the length the cable is to cut the cable and separate th two ends.

Precautions in Handling Cathode-Ray Tube

The trend toward the use of large cathode ray tubes has increased the dangers of implo sion, or collapse of the glass tubes as a resu of atmospheric pressure. The tubes are not dangerous if properly handled; but if they are struck, scratched, dropped, or handled carelessly in any way, they can very well become an instrument of severe injury or death. The following precautions should be taken for the protection of personnel:

1. Wear goggles to protect the eyes from flying glass particles which result from implosion due to fracture of the envelope. The goggles should be of the type which provide side and front protection and which have clear lenses that can stand a rigid impact test.
2. Wear suitable gloves to protect the hands.
3. Be sure that no part of the body is directly exposed to possible glass splinters caused by implosion. Also remember that the coating on some tubes is poisonous if absorbed into the bloodstream.
4. Care of the tube. Do not expose the tube to possible damage. When the tube is needed, remove it from the packing box with caution, taking care not to strike or scratch the envelope. Insert it into the equipment socket cautiously, using only moderate pressure. Do not jiggle the tube. Use these same precautions when removing the tube from the equipment.

When the tube must be set down, it is important that the face be placed on a clean, soft padding. Do not stand directly in front of the face, for accidental implosion may cause it to be propelled directly forward with a velocity sufficient to cause severe injury.

Selenium Rectifiers

When selenium rectifiers burn out, fumes of selenium dioxide are liberated which cause an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is hot since a skin burn might result through which some of the selenium compound could be absorbed.

Disposition of Radioactive Tubes

Radioactive material is now used in quite a number of tubes in fire control systems, guided missile systems, and radar equipment. In radar equipment, these are usually found in the waveguide as ATR or TR tubes, and in some models as spark gap tubes.

The radioactive materials are intentionally added to the tubes to produce a continuous supply of ionized particles in the tubes. This assures that the tubes will always operate at the same voltage. As long as the radioactive tubes are not broken, the radiation hazard is slight, but as soon as the tubes are broken the hazard is increased and radiation sickness is possible. Radiation sickness may be caused when radioactive materials enter the body by eating or drinking, inhalation, or through the skin as by way of an open wound.

HANDLING TUBES: When a radioactive tube has been broken, it is advisable to observe the following rules:

1. No material contaminated by radioactivity should be allowed to come in contact with any part of the body at any time. Rubber or plastic gloves should be worn at all times when the handling of radioactive wastes and broken radioactive parts is involved.
2. No food or drink should be brought into the contaminated area or near any material that is radioactive.
3. Immediately after leaving the contaminated area, personnel handling radioactive material in any way should remove any clothing which may have become contaminated. Hands and arms should be washed thoroughly with soap and water, especially before eating, drinking, or smoking.

DISPOSAL: Radioactive electron tubes should not be disposed of individually. They should be collected in a designated steel container with a tight-fitting lid and suitable markings until a reasonable quantity for disposal has been gathered.

Radioactive waste can be disposed of by burying in soil or by sinking in the ocean. Regulations concerning the disposal of radioactive material are published by the Atomic Energy Commission. Your activity will have specific directives that set forth the procedures that you will follow in disposing of such materials.

Discarded tubes should not be broken purposely as breaking releases radioactive particles into the atmosphere where they may be breathed into the body. When unavoidably broken, the debris should be gathered carefully. Wear rubber or plastic gloves. Pick up large pieces with forceps, and sweep up the fine particles with a vacuum cleaner using disposable collecting bags. If the breaking of tubes is a frequent occurrence, care should be given to selecting the best type of collecting bags. The collecting bags should be sealed in a container such as a plastic bag, ice cream carton, glass jar, or wrapped in heavy waxed paper and then placed in a covered metal container until disposed of by burying or sinking.

FIRST AID PROCEDURE: Where a wound caused by a sharp radioactive particle is sustained, the following first aid procedures are recommended:

1. Immediate application of a tourniquet if the wound is located where a tourniquet is applicable.
2. Stimulation of mild bleeding by manual pressure about the wound and by the use of suction bulbs. Do not suck the wound by mouth.
3. The wound should be washed with soap and flushed with plenty of clean water.
4. If the wound is of the puncture type, or the opening is quite small, an incision should be made to promote free bleeding and to facilitate cleaning and flushing of the wound.

NOTE: The above procedures cannot exclude the hazard of a lifetime tolerance of radioactive material entering a wound resulting from the breaking of a radioactive tube. Further measures to be undertaken in each case should be left to the judgment of the responsible medical officer.

IDENTIFICATION: Tubes that contain radioactive material may be identified by the RADIATION SYMBOL. (See fig. 2-1.) The symbol is printed in magenta (purplish shade of red) color on a yellow background. This marking indicates that this type of tube either singly or in quantity may constitute a handling or storage hazard.

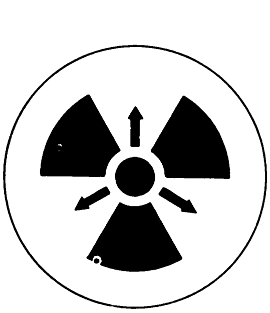


Figure 2-1.—Radiation symbol.

Safety Precautions in Using Tools

As a general precaution, be sure that all tools used conform to Navy standards as to quality and type, and use them only for the purposes for which they were intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools should be returned to supply.

Use only straight, undamaged, and properly sharpened drills. Tighten the drill securely in the chuck by using the key provided; never with wrenches or pliers. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before the drilling operation is started.

When using a portable power drill, grasp it firmly during the operation to prevent it from bucking or breaking loose, thereby causing injury to yourself or damage to the tool.

Care should be taken in selecting the correct type of pliers, side cutters, or diagonal cutters. Pliers or cutters should not be used on nuts or pipe fittings. When cutting short pieces, take care that they do not fly and cause injury. The fingers should not be wrapped around the handle of a tool in such a way that they can be pinched or jammed if the tool slips from the work. The use of extensions on the tool handle to increase leverage is prohibited.

In selecting a screwdriver for electrical work, be sure that it has a nonconducting handle. The screwdriver should not be used as a substitute for a punch or a chisel, and care should be taken that one is selected of the proper size to fit the screw. The point of the screwdriver should be kept in proper shape with a file or a grinding wheel.

Use wrenches only if they are in good condition and are right for the job. Never use a wrench as a hammer and do not put an extension on the handle. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned. When working in a confined space, the worker should take care that the grip he uses will not endanger him.

Soldering Irons

The soldering iron is a fire hazard and a potential source of burns. When soldering cables or wires, keep the iron holder in the open where the danger is minimized. Disconnect the iron when leaving work, even for a short period.

When using the iron keep the ends of wires and cables in such a position that they do no provide a source of injury to the face or eyes Keep your head away from the iron. Do no flip the iron to dispose of molten solder that has accumulated on the tip; a drop may strike you or someone else.

Portable Power Tools

All portable power tools should be carefully inspected before being used to see that they are clean, well-oiled, and in a proper state of repair. The switches should operate normally, and the cords should be clean and free of defects. The casings of all electrically driven tools should be grounded. Sparking portable electric tools should not be used in any place where flammable vapors, gases, liquids or exposed explosives are present.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor be left where they might be run over. They should not be allowed to come in contact with oil, grease, hot surfaces, or chemicals; and when damaged, should be replaced instead of being patched with tape. When unplugging power tools from receptacles grasp the plug not the cord.

Electric Shock

Electric shock may cause instant death or may cause unconsciousness, cessation of breathing, and burns of all degrees. If a 60-cycle alternating current is passed through a person from hand to hand or from hand to foot, the effects when current is gradually increased from zero are as follows:

1. At about 1 milliampere (0.001 ampere) the shock can be felt.
2. At about 10 milliamperes (0.010 ampere) the shock is severe enough to paralyze muscles so that a person is unable to release the conductor.
3. At about 100 milliamperes (0.100 ampere) the shock is fatal if it lasts for one second or more.

IT IS IMPORTANT TO REMEMBER THAT CURRENT IS THE SHOCK FACTOR RATHER THAN THE AMOUNT OF VOLTAGE.

BODY RESISTANCE

It is important for you to know that the resistance of the human body is not great enough to prevent fatal shock from a voltage of as low as 115 volts. In many cases, voltages less than 115 volts are fatal. When the skin is dry it has a high resistance. The resistance may be high enough to protect a person from a fatal shock even if one hand touches B plus while another part of the body touches the chassis or another ground.

Contact resistance decreases when the skin is moist and body resistance may drop to as low as 300 ohms. With this low body resistance, it can be seen that a very low voltage could supply enough current to cause death.

RESUSCITATION FROM THE EFFECTS OF ELECTRIC SHOCK

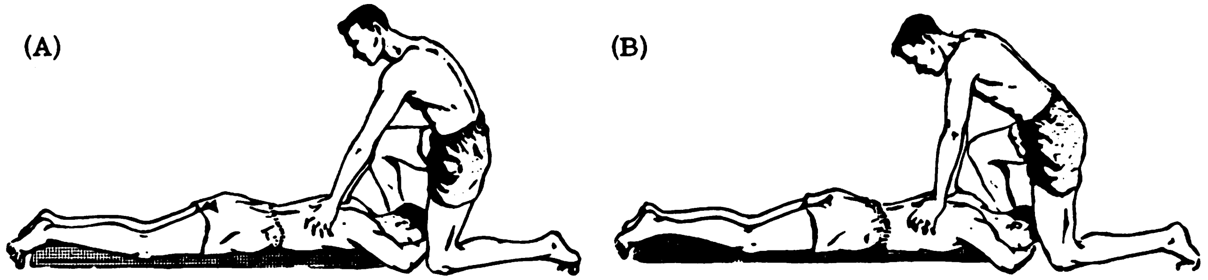
ARTIFICIAL RESPIRATION, the mechanical promotion of breathing, is used to resuscitate persons whose breathing has stopped as a result of electric shock, drowning, asphyxiation from gas, strangling, or the presence of a foreign body in the throat. To revive persons suffering from electrocution resulting in stoppage of breathing, begin artificial respiration immediately. Send another person for a medical officer or other competent medical aid. If there is any serious bleeding, stop it first, but do not waste time on anything else. Seconds count. The longer you wait to begin, the less are the chances of saving the victim.

The approved method of artificial respiration is the back-pressure, arm-lift technique (Holger-Nielson method) which is illustrated in figure 2-2. The back-pressure, hip-lift method is shown in the *Standard First Aid Training Course,* NavPers 10081. This is a method that may be used on a person who has been injured in the upper part of the body.

Place the victim so that he is lying in the face-down, or prone, position. Bend both his elbows and place one of his hands on the other. Turn his face so that it is resting on his hands. Quickly sweep your fingers through his mouth to clear it out and be sure that the throat is open. With the same movement, bring the tongue forward so that it cannot stop the air passage.

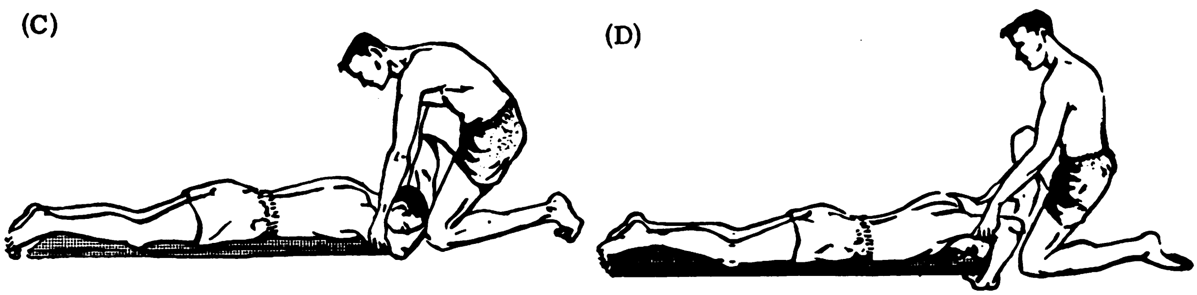
Kneel at the victim's head, facing him. Kneel on either knee or both—whichever is most comfortable.

Next, place your hands on his midback, just below the shoulder blades, so that the fingers are spread downward and outward and the



INITIAL POSITION.

PRESSURE PHASE. NOTE THAT THE OPERATOR'S ARMS ARE STRAIGHT AND NEARLY VERTICAL.



POSITIONING THE HANDS ON THE VICTIM'S ARMS NEAR HIS ELBOWS.

LIFT PHASE. NOTE THAT THE OPERATOR IS LEANING BACK WITH HIS ARMS NEARLY STRAIGHT AND THAT THE VICTIM'S ARMS ARE RAISED ENOUGH TO ARCH HIS BACK AND PARTIALLY RAISE HIS CHEST FROM THE GROUND.

Figure 2-2.—The back-pressure, arm-lift method of artificial respiration.

thumb tips almost touching. This position is shown in (A) of figure 2-2.

Rock forward until your arms are approximately vertical, and allow the weight of the upper part of your body to exert a slow, steady pressure on your hands until firm resistance is met. This action compresses the chest and forces air out of the lungs. Keep your elbows straight and your arms almost vertical so that pressure is exerted downward. This phase is illustrated in (B) of figure 2-2.

Be very careful to avoid exerting sudden or excess pressure, and be sure that your hands are not too high up on the victim's back or on his shoulder blades. Release the pressure quickly. "Peel" your hands from his ribs without any extra push. Now rock backward and allow your hands to come to rest on the victim's arms just above his elbows, as shown in (C) of figure 2-2. As you rock backward, draw his arms upward and toward you. Keep your arms nearly straight, as shown in (D) of the figure.

Lift the victim's arms until you feel resistance and tension at the shoulders. The arm lift pulls on the chest muscles, arches the back, and relieves the weight on the chest, thus pulling air into the lungs. Then lower the arms and you have completed one full cycle.

The whole cycle can be chanted to help you keep the rhythm—"Place . . . Swing forward . . . Swing back . . . Lift." Keep this rhythm without stopping once you have begun. The four steps should take about 5 or 6 seconds, allowing 10 to 12 complete cycles a minute. Don't break the rhythm no matter what else is being done, such as:

1. Keeping the victim warm. If someone is there to help you, have him wrap the patient in clothing or a blanket. This can be done between cycles.
2. Loosen his belt or other tight clothing. Your helper can do this too.
3. Moving the victim. This is only to be done if you must, in case of foul weather, fire, or other hazard. After he is breathing on his own, he may be moved, but only in a lying-down position.

When resuscitating a victim of shock by artificial respiration, do not give up too soon. Sometimes it takes several hours. Be certain that all chance of saving him is gone before you think of stopping.

Keep watching the patient even after he starts to breathe again. If he stops, you must start artificial respiration again immediately. Keep him lying down and warm, even after he comes to. Do not give him anything to drink unless he is fully conscious. If the medical officer has not arrived when the victim regains consciousness, give him some stimulant such as 1 teaspoonful of aromatic spirits of ammonia in a small glass of water, or hot coffee, or hot tea. Do not give the victim alcohol unless you cannot get anything else.

TREATMENT OF THERMAL BURNS

In administering first aid for burns, the objectives are to relieve the pain, to make the patient as comfortable as possible, to prevent infection, and to guard against shock which often accompanies burns of a serious nature.

The greatest pain from a burn is caused by the movement of air over the damaged area. The first step is to cover the burn with some substance which will exclude the air. When the skin is merely reddened and is not broken, cover the burned area with a coating of vaseline, or petroleum jelly. Never put iodine on a burn. Do not apply an antiseptic or a powder; and avoid the use of cotton directly on the burn since it will stick and cause further injury.

If the skin is blistered or if the flesh is cooked and charred, secure the services of a medical officer or a corpsman as soon as possible. If medical aid cannot be obtained in a short period of time, proceed to dress the burned area as follows:

1. Remove charred materials from the affected area, taking care not to break any blisters which may be present. If clothing is stuck to any part of the surface, do not pull it loose but cut around the cloth and let it stay attached.
2. Apply very thin pieces of sterile vaseline gauze over the burned area.
3. Apply cotton wadding, gauze fluffs, or sterile mechanics' waste over the top of the vaseline gauze to give the dressing bulk.
4. Apply elastic bandages to make a snug pressure dressing.
5. Have the patient transferred to a hospital as soon as possible.

For additional information concerning the treatment of burns refer to the *Standard First Aid Training Course*, NavPers 10081.

QUIZ

1. You are working in a poorly ventilated space and your body is moist with perspiration. What minimum voltage could produce fatal shock?
   a. 30 volts direct current
   b. 90 volts alternating current
   c. 110 volts alternating current
   d. 90 volts direct current

2. At what frequency should artificial respiration be applied?
   a. Once every 8 to 10 seconds
   b. Once every 10 to 12 seconds
   c. 4 cycles per minute
   d. 12 cycles per minute

3. What safety precautions should be observed when removing a new cathode-ray tube from its shipping carton?
   a. Goggles and protective clothing should be worn
   b. Rest the tube lightly on its neck
   c. Use nonmagnetic tools
   d. Stand directly in front of the tube whenever possible

4. Which of the following is a recommended cleaning solvent?
   a. Alcohol
   b. Carbon tetrachloride
   c. Dry cleaning solvent P-S-661
   d. Turpentine

5. The minimum safe distance for open flame and smoking in the vicinity of a parked aircraft that is not being refueled is
   a. 25 ft.
   b. 50 ft.
   c. 75 ft.
   d. 100 ft.

6. After a flight has been completed, when may storage batteries be disconnected or removed from an aircraft?
   a. At the discretion of the electrician
   b. After the aircraft has been tied down
   c. After the battery compartment has been aired and an inspection for open switches has been made
   d. At the pilot's request

7. Why is the use of carbon tetrachloride as a cleaning solvent specifically prohibited?
   a. It produces corrosion on metals
   b. The fumes are toxic if breathed
   c. It is very explosive
   d. It takes too long to evaporate

8. In disposing of radioactive materials, they should be
   a. disposed of the same as other waste materials
   b. sent directly to BuAer for screening
   c. buried (or sunk in the sea) according to current instructions
   d. smashed to bits and then burned

9. When using an electric portable tool, be certain that
   a. the casing is grounded
   b. a manual tool will not work as well
   c. you have the Electronics Officer's permission to use the tool
   d. loose clothing is being worn

10. After artificial respiration, when the victim has fully regained consciousness, give him a stimulant to drink composed of
   a. aromatic spirits of ammonia in a small glass of water
   b. baking soda in a small glass of cold water
   c. ice-cold tea or coffee
   d. alcoholic liquor

11. What safety precautions must be taken when repairing an energized circuit?
   a. The repairing should be supervised by the communications or electronics officer
   b. The worker should be well insulated from ground
   c. Helpers should be stationed at main power switches and a man qualified in first aid for electrical shock must be present
   d. All of the above

12. The proper type fire extinguisher to be used on an electrical fire is
   a. foam
   b. fog or water spray
   c. CO_2
   d. any other extinguisher suitable for a class B fire

13. What type of tube contains radioactive materials?
   a. ATR or TR
   b. Thyratron
   c. Mercury vapor
   d. Neon

14. In treating a person for a serious burn, an important step is to
   a. saturate the burned area with iodine to prevent infection
   b. remove all material that is stuck to the burned area
   c. cover the burned area with vaseline or petroleum jelly
   d. pack the burned area in cotton

15. When using side cutters, diagonal cutters, or pliers, the use of extensions on the handles to increase leverage is
   a. permitted if needed
   b. prohibited
   c. permitted in some cases
   d. recommended

16. When a plane is in flight, from whom must the technician obtain permission before operating a radio or radar transmitter?
   a. Navigator
   b. Plane captain
   c. Plane commander
   d. First radioman

17. During refueling, radar equipment should not be operated within how many feet of the aircraft?,
   a. 50
   b. 75
   c. 100
   d. 150

18. Tags attached to the main supply switches to safeguard personnel working on the circuits concerned will be removed by the
   a. OOD
   b. Electronics Officer
   c. man who attached them
   d. chief in charge

TRUE OR FALSE:

19. When a selenium rectifier burns out, th fumes that are liberated cause an overpowering stench but are not poisonous

20. A wound sustained by a known particle o radioactive material need only be cleane with soap and flushed with clean water

21. Tubes that contain radioactive materia can be readily identified by the standar radiation symbol.

22. A puncture type wound sustained by a piec of radioactive material should be furthe cut to facilitate cleansing and promote fre bleeding.

CHAPTER 3

PUBLICATIONS, RECORDS AND REPORTS, PROCUREMENT OF EQUIPMENT

Maintenance Publications

Many different maintenance publications are written to help the Aviation Electronics Technician perform his primary duties of installing, adjusting, maintaining, and testing electronic equipment. The publications that should prove most helpful to you and with which you should become familiar will be described.

NAVAL AERONAUTIC PUBLICATIONS INDEX

This *Index* consists of three separate publications. Each will be discussed. These are originated by the Bureau of Aeronautics and issued by the Chief of the Bureau of Aeronautics. They are kept current through semiannual revisions. As they are published and distributed, they automatically replace and supersede the previous published edition. The *Index* is distributed by BuAer through the Officer in Charge, Naval Air Publications Facility, 700 Robbins Avenue, Philadelphia 11, Pennsylvania. The publications which are listed in the NAPI originate in the following organizations:

1. Chief of Naval Operations
2. Deputy Chief of Naval Operations for Air
3. Bureau of Aeronautics
4. Aviation Supply Office
5. Bureau of Ordnance

Naval Aeronautic Publications Index, NavAer 00-500, Part I

This part contains a complete numerical listing of all available naval aeronautic publications distributed by the Bureau of Aeronautics and stocked for issue as of its date of publication.

The numerical index contains a listing of all available publications by assigned code number and title. It is subdivided into subject groups according to type of aircraft or equipment, or units thereof. A complete breakdown of the subject groups is given in the table of contents in the front of the *Index*.

Publications listed in the *Index* are UNCLASSIFIED unless otherwise marked C (CONFIDENTIAL) in the column headed SECURITY CLASS. Security classifications are kept current through information forwarded from the Security Office, Chief of the Bureau of Aeronautics; and the *Index* reflects the latest information available.

Naval Aeronautic Publications Index, NavAer 00-500A, Part II

This part furnishes a listing that may be used for determining or locating the manuals and publications available for a given aircraft component or equipment. It is referred to as the *Equipment Applicability List*.

All equipments and components are listed in alphanumerical order and all publications pertaining to the subject involved are listed by an assigned number. Instructions for ordering these publications are given in the front of Part I of the *Index*. Another use for the equipment applicability list is to verify that all publications for a certain item of equipment are on hand.

Naval Aeronautic Publications Index, NavAer 00-500B, Part III

This part contains a listing of technical manuals that are applicable to a particular aircraft and its related equipment. The listings in this part are by aircraft model. For example, under the heading F11F-1 every publication pertaining to this aircraft or any piece of its installed equipment is listed numerically under the proper heading.

For each model of airborne electronic equipment, the Bureau of Aeronautics prepares four handbooks. These are: The *Handbook of*

Operating Instructions (HOI), the *Handbook of Service Instructions* (HSI), the *Handbook of Overhaul Instructions* (O/H), and the *Illustrated Parts Breakdown* (IPB). These handbooks, which are authorized for publication by the Chief of the Bureau of Aeronautics, contain information based on the results of countless tests and checks. This information will assist the technician and operator in obtaining the best possible performance from the equipment.

The *Handbook of Operating Instructions* contains information pertaining to the operation of the specific equipment and the necessary checks and adjustments required for obtaining optimum operation. This handbook is divided into the following sections—a general description of the equipment, the operating procedures, the operating checks and adjustments, and provisions for emergency operation of the system.

The *Handbook of Service Instructions* presents information on preparing the specific equipment for use. Also, it tells how to maintain this equipment in an operational squadron, or supporting activity. The handbook is divided into seven sections as follows:

Section I, Description and Leading Particulars

This section gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of units. Also, the electrical, mechanical, and physical characteristics of the particular set and its various units are presented.

Section II, Special Test Equipment and Special Tools

Special test equipment and tools (including test racks) which are used for making a complete bench test of the set or the units are listed in this section of the handbook. Any instructions necessary for modifying the test equipment for some special use or for fabrication of special testing harness are also in this section.

Section III, Preparation for Use and Reshipment

This portion of the handbook shows the method by which the particular equipment should be handled from the time it is received until it is ready for use by the operator. It contains general information on uncrating, assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the units are also included. Applicable data on any checks and adjustments required during installation of the equipment are found in this section.

Section IV, Theory of Operation

A general description of the particular system is presented first. This is followed by detailed explanations of the individual circuits.

Section V, Organizational and Operational Maintenance

This section provides the instructions essential for the maintenance of the equipment and indicates the maintenance activities which perform such work. Included are the preflight and daily inspections and tests, the bench-test procedures, and the troubleshooting methods to be used.

Section VI, Field Maintenance

The instructions required for servicing the equipment at the field maintenance levels are presented in this section. In addition to alinement and parts removal procedures, information is given for checking unit functions by means of performance checks. Procedures for trouble isolation are also given. These procedures will assist in localizing a defective part or assembly to a circuit or group of circuits.

Section VII, Diagrams

Diagrams to be used when maintaining the particular set are contained in this section These include complete schematic, wiring voltage, and resistance diagrams of the se and its units. Also included are cabling charts for connection of the equipment units.

ELECTRONIC MATERIAL CHANGES

Electronic Material Changes (EMC's) are issued by the Bureau of Aeronautics to promulgate technical instructions necessary for the addition, removal, or replacement of part, modification to circuitry, and other necessary changes. Modification of electronic material will normally be limited to modification of parts, subassemblies, assemblies, units or sets, and interconnecting wiring.

Instructions for the substitution of units of an electronic system may be contained in an Electronic Material Change provided the substitution is defined as removal of a set or unit and its replacement with a similar set or unit to perform the same or additional functions.

Electronic Material Changes are mandatory and must be complied with as directed in the change. All activities operating aircraft must maintain a complete file of effective EMC's.

A listing of the effective EMC's are contained in the *Naval Aeronautic Publications Index*, Part I, NavAer 00-500.

ELECTRONIC MATERIAL BULLETINS

Electronic Material Bulletins (EMB's) are issued by the Bureau of Aeronautics to promulgate technical information on operation, inspection, alinement, maintenance procedures, and so forth. These bulletins are listed in the *Naval Aeronautic Publications Index*, Part I, NavAer 00-500.

AIRCRAFT SERVICE CHANGES

Aircraft Service Changes are a series of publications which apply to a definite type of aircraft. They relate to the entire aircraft. Many of the changes refer to manufacturer's specifications.

Service Changes are issued in numerical order and at irregular intervals. Each publication issued indicates when the change is to be made and the reason for the change.

These Aircraft Service Changes may be issued under any one of the following classifications:

IMMEDIATE ACTION—change shall be incorporated prior to further flight of the specified aircraft.

URGENT ACTION—changes which have an effective date shall be incorporated not later than the next intermediate inspection, or the next major inspection, with the aid of higher class maintenance activities if necessary.

ROUTINE ACTION—changes which have an effective date are to be incorporated at the next overhaul or special modification period. When considered necessary, major operating commands may designate specific changes to be incorporated by activities under their control.

BUAER INSTRUCTIONS

BuAer Instructions contain permanent instructions from the Bureau of Aeronautics to all naval activities supporting aircraft or the aeronautical program. They contain instructions and information primarily concerned with policy, administration, and air operation. All commands operating aircraft are required to maintain a file of all effective BuAer Instructions.

BUAER BULLETINS

BuAer Bulletins cover the same kinds of material as the BuAer Instructions but are of a temporary nature. A file must be maintained of all effective BuAer Bulletins.

TECHNICAL ORDERS

Technical Orders (TO's) are used to disseminate instructions of a technical nature concerning naval aircraft and equipment. They relate to the operation, maintenance, inspection, and storage of aircraft and equipment with the exception of electronic equipment. TO's are mandatory and must be incorporated upon receipt or by the time stated in the TO.

These orders are numbered numerically by the year. The first publication of each year (numbered 00) is an index of all effective TO's. All commands operating aircraft must maintain a complete file of effective TO's.

TECHNICAL NOTES

Technical Notes (TN's) contain technical data of an operational or maintenance nature concerning aircraft or equipment under the cognizance of the Bureau of Aeronautics. Some of these instructions are mandatory and some are not, depending upon their content. All commands maintaining aircraft must maintain a complete file of TN's that are in effect. They are numbered in the same manner as Technical Orders.

DIGEST—U.S. NAVAL AVIATION ELECTRONICS

Each month the Naval Aviation Electronics Service Unit (NAESU) prepares and publishes the magazine *Digest of U. S. Naval Aviation*

Electronics. The *Digest* contains information on electrical and electronic equipment relative to operation, maintenance, installation, and supply. This is an excellent source of information dealing with new equipment and new ideas on the older equipment. It gives the latest procedures developed by NAESU and other activities, for speeding the testing, calibratio and alinement of equipment. In general, it i as the name suggests a "digest" of all the lates information pertaining to your work in electronics. It should be on the "must read" lis for all hands, and always available for read reference.

Instructions and Notices

A system is in use throughout the Navy for the issuance of directive-type releases including those which prescribe policy, organization, methods, or procedures, and those which contain information. Certain publications, such as established manuals, operational releases, technical publications, some classified matter, and those joint Army-Navy-Air Force publications which are numbered serially, and not having separate Army or Air Force designations, form the system.

This program is called the Navy Directives System and provides a uniform method for issuing and maintaining directives. Conformance to the system is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan: Instructions and Notices.

INSTRUCTIONS are directives which contain information or require action of a continuing nature. An Instruction has permanent reference value and is effective until the originator supersedes or cancels it.

NOTICES are directives of a one-time nature and contain information or require action which can be completed immediately. A Notice does not have permanent reference value and contains provisions for its cancellation.

For reasons of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation, the type of release (whether an Instruction or Notice), a subject classification number; and in the case of Instructions only, a consecutive number. Because of their temporary nature, the consecutive number is not assigned to Notices. Identification and filing information is assigned by the originator and is placed on each page the release.

The manner of numbering and identifyi directives can be understood better by considering a typical identifier:

SECNAV	INST.	5215.	1A
(a)	(b)	(c)	(d)

(a) This is the authorized abbreviation the originator of the directive.

(b) This part refers to the type of releas in this case an Instruction.

(c) This is the subject number which determined by the subject matter of the directive and is obtained from the Table of Subje Classification Numbers.

(d) Following the period is the consecuti number which is found only in Instruction An originator would assign consecutive numbers to those consecutive instructions with t same Subject Classification Number. In t example above the Subject Classification Number 5215 concerns Issuance Systems. If t originator, SecNav, issued additional Instructions dealing with issuance systems, they wou be assigned number 5215.2A, 5215.3A, 5215.4 and so forth. Subject classification numbe are listed in the Table of Subject Classificati Numbers found in SecNav Instruction 5215.1 This table contains a numerical and alphabeti listing of subjects, and is of considerable val for reference use when information or instructions of a particular nature are desir This instruction contains all necessary information concerning the use and procedu of the Navy Directives System.

Records and Reports

MATERIAL RELIABILITY REPORTS

There are two basic forms entitled *Failure, Unsatisfactory, or Removal Report,* NavAer 3069 and *Electronic Failure Report,* Form 787, for reporting all failures, faults, or malfunctions of aeronautical material. Both a simplified check-box forms that require v little detailed writing. Provision is included to amplify both reports by the addition of narrative data, if conditions of the fault or failure warrant it. For simplicity, the *Failure, Unsatisfactory, or Removal Report* is designated as the FUR, and the *Electronic Failure Report* as the EFR.

The Electronic Failure Report (EFR)

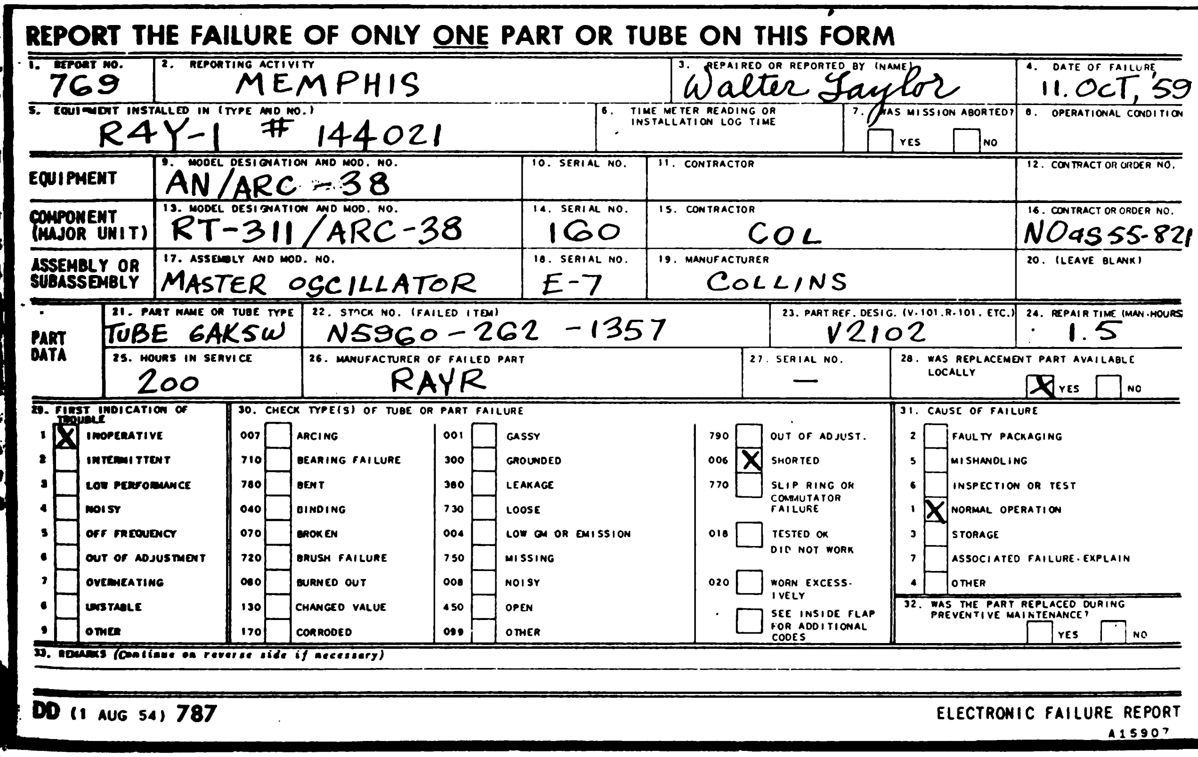
The purpose of the EFR is to provide the Bureau of Aeronautics with up-to-date information on equipment failures and reliability. They are prepared and submitted for all failures or unsatisfactory conditions of electron tubes and electronic or electrical parts, sets, or systems.

The EFR is prepared by the technician who actually located the trouble or repaired the electronic equipment. A report must be submitted for each failure that occurs, or upon determining that a part or tube is defective or unsatisfactory for any reason. In cases where two or more associated parts are found to be defective, and doubt exists as to which part is primarily at fault, each suspected part must be reported separately. Each report must refer to all other reports of the associated failu All reports of a multiple failure of the as ciated parts should then be fastened toget to permit rapid evaluation.

In general, EFR's will be submitted with amplifying remarks. However, when in opinion of the reporting activity the repor condition may more readily be evaluated by inclusion of narrative comments, such may included in the "Remarks" space on the f of the form and continued on the reverse s or on separate bond paper and attached to EFR. These remarks should describe conditions concerning or preceding failure malfunction, or of recommended remec measures. Unnecessary use of the "Remarl space, or meaningless comments should avoided since this delays data processing.

EFR's should be submitted daily. Th reports that include amplifying remarks photographic enclosures may be delayed as many as three days.

When preparing the EFR, DD 787 (fig. 3- it is necessary to make all required entr to insure maximum benefit from the syste The entries on this form should be comple as follows:



REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. REPORT NO. 769
2. REPORTING ACTIVITY MEMPHIS
3. REPAIRED OR REPORTED BY (NAME) Walter Taylor
4. DATE OF FAILURE 11. OCT, '59
5. EQUIPMENT INSTALLED IN (TYPE AND NO.) R4Y-1 # 144021
6. TIME METER READING OR INSTALLATION LOG TIME
7. WAS MISSION ABORTED? ☐ YES ☐ NO
8. OPERATIONAL CONDITION

EQUIPMENT	9. MODEL DESIGNATION AND MOD. NO. AN/ARC-38	10. SERIAL NO.	11. CONTRACTOR	12. CONTRACT OR ORDER NO.
COMPONENT (MAJOR UNIT)	13. MODEL DESIGNATION AND MOD. NO. RT-311/ARC-38	14. SERIAL NO. 160	15. CONTRACTOR COL	16. CONTRACT OR ORDER NO. NO4S55-821
ASSEMBLY OR SUBASSEMBLY	17. ASSEMBLY AND MOD. NO. MASTER OSCILLATOR	18. SERIAL NO. E-7	19. MANUFACTURER COLLINS	20. (LEAVE BLANK)

PART DATA

21. PART NAME OR TUBE TYPE TUBE 6AK5W
22. STOCK NO. (FAILED ITEM) N5960-262-1357
23. PART REF. DESIG. (V-101, R-101, ETC.) V2102
24. REPAIR TIME (MAN-HOURS) 1.5
25. HOURS IN SERVICE 200
26. MANUFACTURER OF FAILED PART RAYR
27. SERIAL NO. —
28. WAS REPLACEMENT PART AVAILABLE LOCALLY ☒ YES ☐ NO

29. FIRST INDICATION OF TROUBLE

1 ☒ INOPERATIVE
2 ☐ INTERMITTENT
3 ☐ LOW PERFORMANCE
4 ☐ NOISY
5 ☐ OFF FREQUENCY
6 ☐ OUT OF ADJUSTMENT
7 ☐ OVERHEATING
8 ☐ UNSTABLE
9 ☐ OTHER

30. CHECK TYPE(S) OF TUBE OR PART FAILURE

007 ☐ ARCING
710 ☐ BEARING FAILURE
780 ☐ BENT
040 ☐ BINDING
070 ☐ BROKEN
720 ☐ BRUSH FAILURE
080 ☐ BURNED OUT
130 ☐ CHANGED VALUE
170 ☐ CORRODED
001 ☐ GASSY
300 ☐ GROUNDED
380 ☐ LEAKAGE
730 ☐ LOOSE
004 ☐ LOW GM OR EMISSION
750 ☐ MISSING
008 ☐ NOISY
450 ☐ OPEN
099 ☐ OTHER
790 ☐ OUT OF ADJUST.
006 ☒ SHORTED
770 ☐ SLIP RING OR COMMUTATOR FAILURE
018 ☐ TESTED OK DID NOT WORK
020 ☐ WORN EXCESSIVELY
☐ SEE INSIDE FLAP FOR ADDITIONAL CODES

31. CAUSE OF FAILURE

2 ☐ FAULTY PACKAGING
5 ☐ MISHANDLING
6 ☐ INSPECTION OR TEST
1 ☒ NORMAL OPERATION
3 ☐ STORAGE
7 ☐ ASSOCIATED FAILURE-EXPLAIN
4 ☐ OTHER

32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? ☐ YES ☐ NO

33. REMARKS *(Continue on reverse side if necessary)*

DD (1 AUG 54) 787

ELECTRONIC FAILURE REPORT

A15907

Figure 3-1.—Electronic Failure Report.

Space 1. Report Number. Each reporting activity will assign serial numbers to reports, starting with number 1 at the beginning of each calendar year and progressing through number 999. When reports from any activity exceed 999, the serials recommence with number 1. This cycling will be repeated as often as necessary during the calendar year. Do not use a calendar year suffix with this serial.

Space 2. Reporting Activity. Enter the name of the activity originating the report. Normally, this is the activity performing the maintenance or the custodian of the item at the time of reporting. Abbreviated administrative titles without prefixes shall be used, such as VA-146, VX-1, FAETUPAC, Pt. Mugu, Quonset Pt., and so forth. Squadron detachments or units should use the parent squadron number and the detachment number or letter.

Space 3. Repaired or Reported By. The EFR should be signed by the person actually finding the trouble, or performing the maintenance or repair. Local procedures will be established for the review of EFR's by competent authority prior to submission.

Space 4. Date of Failure. Insert date fault or failure was actually reported or found.

Space 5. Equipment Installed In (Type and No.). Insert the model AND the bureau number of the aircraft in which the fault or failure occurred. When fault or failure is found during bench check of the equipment, insert the word BENCH. Do not use squadron aircraft numbers in lieu of the official bureau number.

Spaces 6, 7, and 8 are not used by naval aeronautical activities.

Space 9. (Equipment) Model Designation and Mod Number. Insert the recognized designation of the system or set in which the failure occurred, such as ARC-27, ARN-21, APS-38, and so forth.

Space 10. Serial Number. This space will be used only when the set is a self-contained unit. When the failure occurs in a unit of a set, space 14 will be used.

Space 11. Contractor. When the equipment noted in space 9 is a self-contained unit, enter the proper code for the manufacturer.

Space 12. Contract Number. Complete only when the equipment in space 9 is a self-contained unit.

Space 13. (Component) Model Designation and Mod Number. This entry is the one most commonly used in failure studies and will be used in preference to space 9 when the failure occurs in any unit of an equipment. Entry will include complete designation, such as RT-311/ARC-38, AM-1234/ASA-13, SN-36B/APS-31, and so forth.

Space 14. Serial Number. Enter the seria number of the unit (black box) in which faile part is located. This is obtained from th nameplate.

Space 15. Contractor. Enter the code letters for the manufacturer of the unit in whic failed part is located. This code is usually o the nameplate or in applicable handbooks.

Space 16. Contract Number. Enter th contract, or order number for the unit in whic failure occurred, when such information i available from the nameplate or other source

Spaces 17, 18, 19, and 20. Use only whe applicable. Information required is simila to that required for a unit and will be furnishe only when a subassembly is specifically identified by these entries.

Space 21. Part Name or Tube Type. Ente the recognized name of the failed part (capacitor, resistor, motor, tube, etc.) and the tub type for tube failures (tube 5654, tube 6X4-W etc.). If a complete subassembly is replace enter the type, such as IF amplifier, spectru amplifier, indicator, and so forth.

Space 22. Stock Number. Enter the corre stock number OF THE FAILED PART as obtained from Navy Stock Lists, Section R Allowance Lists, or applicable equipment handbook

Space 23. Part Ref. Designator. Enter t part reference designator (symbol number) the failed part, such as B-101, R-304, V-2 and so forth, as determined from the circu diagram of the handbook for the particul equipment. Certain subassemblies may ha no part reference designator, such as subassemblies for AN/ARC-27 set, and are identifi only as 100-200, 400-600 and so forth. In the cases record the complete group numb (100-200).

Space 24. Repair Time. Enter the actu time required to isolate and repair the troub reported. This time should be noted for t isolation and replacement of a single pa Where several parts contribute to an equi ment and separate reports are submitted, t time for replacing each item should be ca culated separately.

Space 25. Hours in Service. Enter the be available operating time on the item since n or overhauled. If elapsed time meters are installed and no maintenance records a available, enter a reasonably accurate estim of time in service using aircraft log time a considering operational requirements of the equipment in service. THIS ENTRY MUST BE COMPLETED ON EACH EFR.

Space 26. Manufacturer of Failed Part. When available, enter the code for the manufacturer of the failed part. Reports concerning electron tubes should always contain this entry. Correct codes are contained in the *Aviation Supply Office Catalog,* Section 0003.

Space 27. Serial Number. This space should be completed only when the failed part contains a serial number, as may be found on certain magnetrons and klystrons.

Space 28. Was Replacement Part Available Locally? Check YES if replacement part was available in shop stores or in local supply stocks, otherwise check NO.

Space 29. First Indication of Trouble. Check the ONE box which most appropriately describes the first indication of a fault or failure.

Space 30. Check Type of Part Failure. Check the ONE box which most appropriately describes the real or suspected condition of the part replaced.

Space 31. Cause of Failure. Check the ONE box most descriptive of the cause for the part failing.

Space 32. Was the Part Replaced During Preventive Maintenance? Check as appropriate.

Space 33. Remarks. Enter all historical or engineering comments when available and when a failure warrants it. Comments may be continued on the reverse of the form or on separate sheets of bond paper and attached to the report. Photographs (8 x 10 inch, glossy finish), drawings, or sketches should be attached to the EFR when such matter will assist in determining the areas or causes of failure.

Failure, Unsatisfactory, or Removal Report (FUR)

The multiple-copy FUR is used to report failure when a faulty set, unit, or assembly must be REPLACED by obtaining a NEW replacement from supply, and turning the old one in for repair or credit. Under these circumstances the preparation of Form DD 1150, Request for Issue or Turn-In, is not required and the FUR "RM" copies become official accountable documents.

A single-copy FUR is used when no turn-in to supply is made.

The multiple-copy FUR form consists of eight sheets separated by carbon paper to comprise a pad or set. The eight sheets are: Failure, Unsatisfactory, or Removal Report (1); File copy (1); Documents for Returning Material (3); Memorandum Request for Material (2); and Tag (1). When completing these forms, use a ballpoint pen or typewriter.

Amplifying remarks are to be noted in space 26 of the FUR and may be continued on a separate sheet of paper as necessary when the remarks can present a better explanation for the failure. The FUR then becomes an AMPFUR (amplified failure or unsatisfactory report). When in the opinion of the reporting activity the subject requires immediate remedial action, the report may be assigned priority as an URGENT AMPFUR. When in the opinion of the reporting activity the subject relates directly to flight safety, the report will be assigned priority as a FLIGHT SAFETY AMPFUR.

All AMPFUR's, URGENT AMPFUR's, and FLIGHT SAFETY AMPFUR's receive individual attention at the Bureau of Aeronautics. Regular FUR's are used for quantitative analysis.

Complete information on the EFR and the FUR reports is contained in the applicable BuAer Instruction.

BUREAU OF AERONAUTICS STANDARD INVENTORY LOGS

The purpose of the Standard Inventory Log is to maintain continuous custodial responsibility of naval aircraft. No aircraft can be transferred or accepted without a Standard Inventory Log, except for experimental types of aircraft.

The following rules govern the listing of items in the Standard Inventory Logs:

1. Items essential to the execution of the designated missions of the aircraft, such as armament, electronics, photographic equipment, and special instruments are included.
2. Items of equipment that are integral parts of the aircraft are excluded. For example, engines, propellers, wheels, tires, and so forth.
3. Special equipment conducive to the comfort or safety of the crew are included, such as liferafts, thermos bottles, bedding, and fire extinguishers.
4. Loose equipment delivered with the aircraft are included, such as mooring kits, and hatch covers.

5. Items subject to pilferage or readily converted to personal use are included, such as clocks, binoculars, and first aid kits.

The Department of Defense has developed a new inventory form called the Aircraft Inventory Record. This form is used with all new production type aircraft of all the services. Standard Inventory Logs on existing aircraft will not be converted to this newer form. The two forms serve the same purpose but originate from different sources.

AIRCRAFT INSPECTION CHECK SHEETS

Periodic maintenance inspections are performed on all aircraft and aircraft systems. Maintenance activities use check sheets when performing these inspections. These sheets itemize all units or assemblies to be inspected. The person performing the inspection must initial the sheet to indicate that the work has been completed. These check sheets are prepared from the *Handbook of Inspection Requirements Daily and Preflight* and the *Handbook of Inspection Requirements Intermediate and Major* for the particular aircraft.

The *Handbook of Inspection Requirements Daily and Preflight* is composed of the master copy of the Daily and Preflight Inspection Check Sheet(s) for that aircraft. These check sheets break down the daily and preflight inspection by aircraft sections and systems.

The *Handbook of Inspection Requirements Intermediate and Major* is composed of two parts. Part 1 contains general instructions, definitions, special inspections, replacement schedules, and a listing of applicable references. Part 2 is a master copy of the Intermediate and Major Inspection Check Sheet(s), organized by systems, including entry space for additional work to be performed, discrepancies noted and corrected, and parts added and removed during the inspection.

The various types of inspections (major, intermediate, daily, and preflight) that you will be required to perform are described in chapter 8 of this training course.

MAINTENANCE AND REPAIR RECORDS

Equipment History Cards

Electronic Equipment History Card, NavShips 536, is the basic maintenance history card for electronic equipment. This card is used as a record of failures and other pertinen information on electronic equipment. It i designed so that when properly filled in, muc of the information is readily available fo partial completion of the Electronic Failur Report. The heading of the history card shoul be typed, but entries on the body may be type or written in ink or indelible pencil.

The right-hand column heading (Dat NavShips-383 Mailed) may be ruled out, an this column used to log the number of the Electronic Failure Report (EFR) sent in for thi particular entry.

Record of Electronic Material Changes

You will be required to make changes t electronic equipment in accordance with BuAe directives. The maintenance department c your activity will receive these changes an pass them on to your division in the form c work orders. As these changes are made, record must be kept so that you can rapidl evaluate the status of all of your equipmen

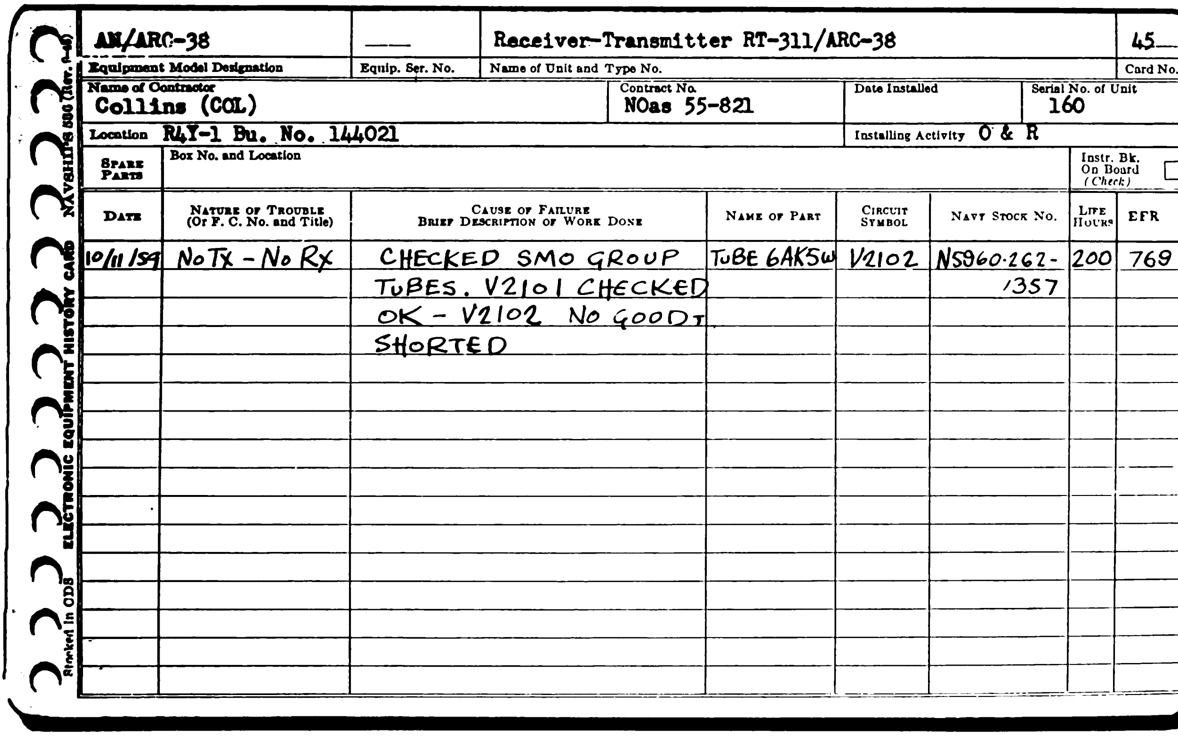
The maintenance department of your activit must be kept posted on the changes that ar made. This is usually accomplished by completing the work orders that are issued by th maintenance department and then returnin them to the maintenance office.

In addition to your routine maintenance worl additional work of a special nature may als be performed. This special work is prescribe by work orders that are issued by the maintenance officer. If the work is of a "one-time nature, it will be issued on a SERIAL WOR ORDER; if it is performed periodically, it wi be issued on a STANDING WORK ORDER.

The change or changes that are made shou be noted on the equipment history card for tl particular piece of equipment.

Work Logs

Electronics maintenance shops use a wo log to keep a record of work performed by tl technician. The entries in this log usually co sist of the serial number of the work order, tl aircraft number, date, repairs completed, a man-hours involved. There is also a space f the person's name or initials who perforn the work, plus a space for the supervisor initials. Normally, the ledger type record bo is used as the work log.



Stocked in ODB ELECTRONIC EQUIPMENT HISTORY CARD NAVSHIPS 536 (Rev. 1-48)

AN/ARC-38	——	Receiver-Transmitter RT-311/ARC-38	45
Equipment Model Designation	Equip. Ser. No.	Name of Unit and Type No.	Card No.

Name of Contractor Collins (COL)	Contract No. NOas 55-821	Date Installed	Serial No. of Unit 160
Location R4Y-1 Bu. No. 144021		Installing Activity O & R	
Spare Parts	Box No. and Location		Instr. Bk. On Board (Check) ☐

Date	Nature of Trouble (Or F. C. No. and Title)	Cause of Failure Brief Description of Work Done	Name of Part	Circuit Symbol	Navy Stock No.	Life Hours	EFR
10/11/59	No Tx - No Rx	CHECKED SMO GROUP	TUBE 6AK5W	V2102	N5960-262-	200	769
		TUBES. V2101 CHECKED			/357		
		OK - V2102 NO GOOD T					
		SHORTED					

Figure 3-2.—History card, electronic equipment.

Procurement of Equipment

To maintain a high degree of aircraft avail- bility, your activity must have an adequate pply of spare parts and materials. You as AT must be able to obtain quickly those rts necessary for repair of your electronic uipment. You should know where to obtain stock numbers for these parts and the pro- dures for ordering. In order to keep track material on order and material received, a cord must be kept.

The amount of maintenance spares and parts our activity is permitted to have on hand is ntrolled by the Bureau of Aeronautics. The uAer *Initial Outfitting Lists* and *Allowance sts* set forth the amount of this material a rticular activity should have.

AERONAUTICAL ALLOWANCE LISTS

eronautical allowance lists are lists of pment and material determined from known stimated requirements as necessary to and maintain aeronautical activities in a rial readiness condition. These lists are mprised of BuAer allowance lists (except advanced base lists), BuAer initial outfit lists, and BuAer tables of basic allowan

Publications identified as BuAer allow lists apply to "shop and/or operational" items and actually spell out initial outfit allowances and material readiness requ ments for such items.

Publications identified as BuAer in outfitting lists apply to "supply-stock usage" type items (maintenance parts and sumables) and merely spell out the range quantities of such items that are to be n available at the time of initial outfitting. Th after, the range and quantities of these it are to be as dictated by local usage and quirements.

Publications identified as BuAer table basic allowances are combinations of " and/or operational" and "supply-stock usage" type items.

These lists are divided into sections w pertain to operating equipment, the airc and equipment of the aircraft. Each sectic designated by a letter such as A, B, R, o Some sections are issued as individual publ tions while other sections are issued series of publications, each of which pertains to a specific model of equipment or aircraft.

Section R is a series of publications issued for specific squadrons, vessels, units, or other activities engaged in the support and operation of aviation electronic equipment and material. These lists indicate allowances of electronic equipment, electronic test equipment, and material required by maintenance and operating activities for the support of installed aeronautical electronic equipment. The technician should be familiar with this section.

Standard Aeronautical Electronics Material, Section R (NavAer 00-35QR-4)

This is an Initial Outfitting List. It lists common resistors, capacitors, and other parts that are used in three or more different equipments. For example, if a particular resistor that is used in the AN/ARC-27 is also used in two other equipments, it is deleted from the Section R for the AN/ARC-27 and carried in this list. It is important to remember that if an item can not be found in the allowance list for a particular type of equipment, it will be found in the NavAer 00-35QR-4 allowance list.

Aeronautical Electronic Test Equipment, Section R (NavAer 00-35QR-5)

This list sets forth allowances of aeronautical electronic test equipment required for the support of installed aeronautical electronic equipment. It also indicates quantities of test equipment maintenance parts, which will not affect the circuitry or calibration of the test equipment. Quantities of batteries estimated to be required at the time of initial outfitting for ninety days support of the test equipment items to which applicable are also listed.

Aeronautical Electronic Accessories, Section R (NavAer 00-35QR-6)

This list contains accessories that have common usage with many different types of electronic equipment, such as microphones, headsets, and antenna insulators.

Electron Tubes used in Aeronautical Electronic Equipment, Section R (NavAer 00-35QR-7)

This Initial Outfitting List is a listing of equipments requiring electron tube support. The equipments are arranged alphabetically and numerically. The type, stock number, and quantity of each tube used by the equipment are given.

The remainder of the Section R series BuAer Initial Outfitting Lists are numbere from 00-35QR-31. Each number represents list for a particular electronic set. For ex ample, the list numbered 00-35QR-182 is listing of maintenance parts for the AN/ARN 21 equipment.

The list number for a particular electron set may be found in the *Naval Aeronautic Pu lications Index*, Part I (NavAer 00-500).

Another section that the electronics tec nician should be familiar with is the Secti U Allowance List (NavAer 00-35QU-1). Th is a listing of standard hand tools for aircra maintenance activities.

The items are listed numerically by Feder Supply Group and alphabetically within ea class.

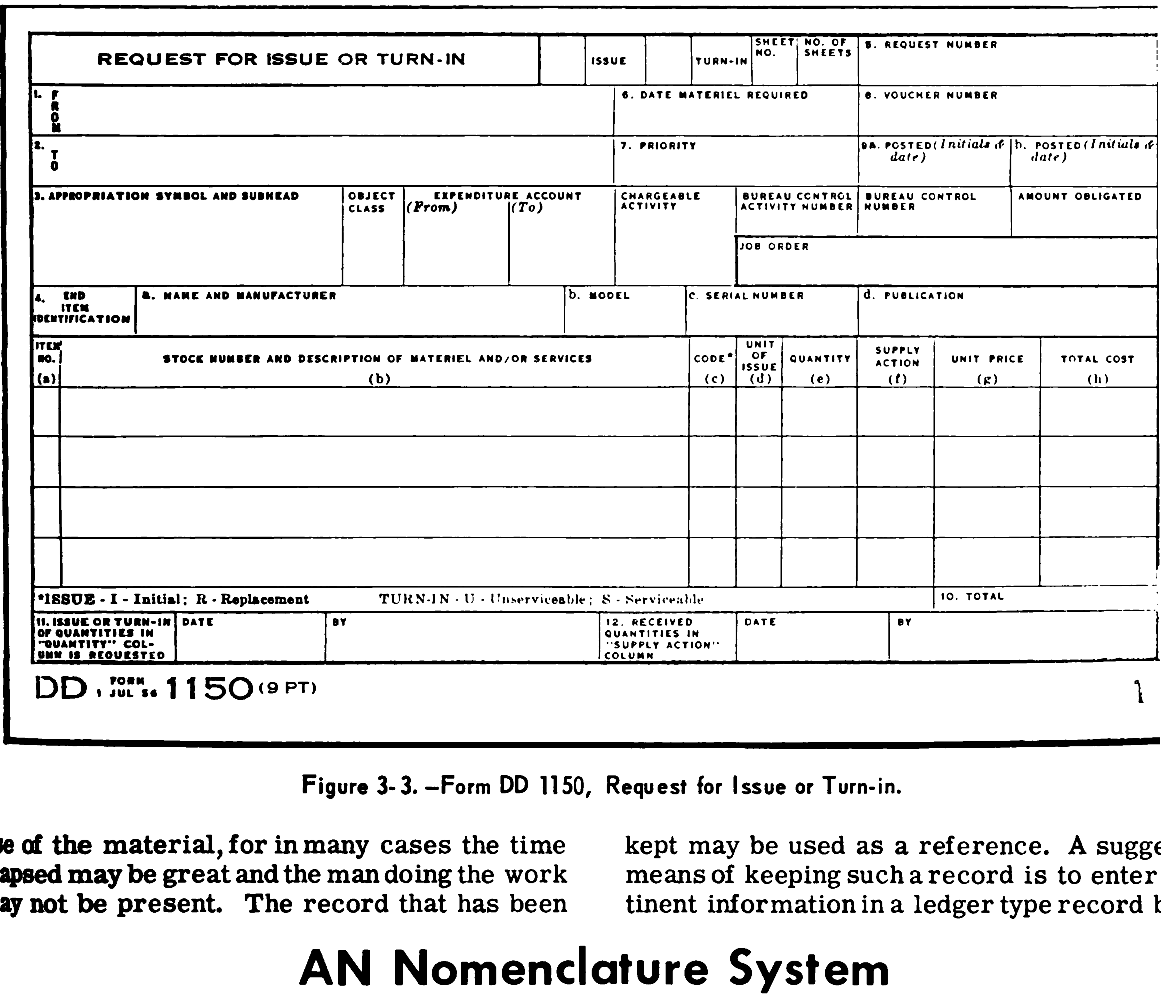
SHOP REQUISITION OF EQUIPMENT AND PARTS

Since all naval activities draw equipme from a central supply point, standardized re uisition forms are used. Aside from the stan ard forms described here, many local ty forms are in use. These local forms are issu by local supply activities to simplify the proce of requisitioning material. However, when lo forms are used, the supply activity must co plete standard forms on the items request

Defense Department Forms DD 1150 and 1150A, *Request for Issue or Turn-in,* are us by activities, both ashore and afloat to requi tion or turn in materials. (See fig. 3-3.)

Form DD 1150 (white) is used to requisit materials and is prepared in multiple copi Local requirements determine the number copies to be prepared. Each class of mater must be requisitioned on separate sets forms. Form DD 1150A is used to turn materials and is yellow in color. It also m be prepared in multiple copies with each utilized for only one class of material.

A record of the material that you have order will serve many functions. There be many instances when there is confusi loss of time, and misunderstanding in relat to whether or not a certain item has b ordered. Unless a record is kept there be uncertainty until the item is received correspondence regarding the order pres some evidence. Records of material orde will not only enable you to ascertain if it ordered, but also the priority, date, by wh ordered, and for what unit of equipment. A this information will aid in the installatio



REQUEST FOR ISSUE OR TURN-IN | ISSUE | TURN-IN | SHEET NO. | NO. OF SHEETS | 5. REQUEST NUMBER

1. FROM | 6. DATE MATERIEL REQUIRED | 8. VOUCHER NUMBER

2. TO | 7. PRIORITY | 9a. POSTED (*Initials & date*) | b. POSTED (*Initials & date*)

3. APPROPRIATION SYMBOL AND SUBHEAD | OBJECT CLASS | EXPENDITURE ACCOUNT (*From*) (*To*) | CHARGEABLE ACTIVITY | BUREAU CONTROL ACTIVITY NUMBER | BUREAU CONTROL NUMBER | AMOUNT OBLIGATED

JOB ORDER

4. END ITEM IDENTIFICATION | a. NAME AND MANUFACTURER | b. MODEL | c. SERIAL NUMBER | d. PUBLICATION

ITEM NO. (a)	STOCK NUMBER AND DESCRIPTION OF MATERIEL AND/OR SERVICES (b)	CODE* (c)	UNIT OF ISSUE (d)	QUANTITY (e)	SUPPLY ACTION (f)	UNIT PRICE (g)	TOTAL COST (h)

*ISSUE - I - Initial; R - Replacement TURN-IN - U - Unserviceable; S - Serviceable | 10. TOTAL

11. ISSUE OR TURN-IN OF QUANTITIES IN "QUANTITY" COLUMN IS REQUESTED | DATE | BY | 12. RECEIVED QUANTITIES IN "SUPPLY ACTION" COLUMN | DATE | BY

DD FORM 1 JUL 56 1150 (9 PT) 1

Figure 3-3. —Form DD 1150, Request for Issue or Turn-in.

use of the material, for in many cases the time lapsed may be great and the man doing the work may not be present. The record that has been kept may be used as a reference. A sugge means of keeping such a record is to enter tinent information in a ledger type record b

AN Nomenclature System

The Joint Communication-Electronic No-enclature System ("AN" System), formerly own as the Joint Army-Navy Nomenclature ystem, is designed so that its indicators will ll at a glance many things pertinent to the em. For example, it tells whether the item s a set or a component and such other information as where it is used, the kind of equipment, d its purpose.

An indicator for a complete set begins with e letters AN. This is followed by a slant bar and a three-letter group. The three lette the second group give the general nature o installation, the type of equipment, anc purpose of the equipment, respectively. lowing the three-letter group is a nu which indicates the specific model of the e ment. An example of the basic designati AN/ARC-38. As can be seen in table 3-1 letters following the slant bar mean airbo radio communications.

Table 3-1.—Set indicator letters.

Installation	Type of equipment	Purpose
Airborne (installed and operated in aircraft).	A--Invisible light, heat radiation.	A--Auxiliary assemblies complete operating sets
Underwater mobile, submarine	C--Carrier.	B--Bombing.
Air transportable.	D--Radiac.	C--Communications (recei and transmitting).
Pilotless carrier.	E--Nupac (nuclear protection and control).	D--Direction finder.

Table 3-1.—Set indicator letters—Continued.

Installation	Type of equipment	Purpose
F--Fixed. G--Ground, general ground use (includes two or more ground installations). K—Amphibious. M—Ground, mobile (installed as operating unit in a vehicle which has no functions other than transporting the equipment). P—Pack or portable (animal or man). S--Water surface craft. T--Ground, transportable. U--General utility (includes two or more general installation classes, airborne, shipboard, and ground). V--Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks). W—Water; surface and undersurface.	F--Photographic. G--Telegraph or teletype. I--Interphone and public address. J--Electromechanical (not otherwise covered). K--Telemetering. L--Countermeasure. M—Meteorological. N--Sound in air. P--Radar. Q--Sonar and underwater sound. R--Radio. S--Special types (magnetic, etc.) or combination of types. T--Telephone (wire). V--Visual and visible light. W--Armament (peculiar to armament, not otherwise covered). X--Facsimile or television.	E--Ejection and/or release. G--Fire control or searchligh directing. H--Recording and/or reproduc ing (graphic, meteorologi cal, and sound). M—Maintenance and test as semblies (including tools N--Navigational aids (includin altimeters, beacons, com passes, racons, depth sound ing, approach and landing Q--Special or combination purposes. R--Receiving, passive detec ing. S--Detecting and/or range ar bearing. T--Transmitting. W—Control. X--Identification and recogn tion.

When the system just described is applied to a unit of the complete set, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of the unit in question. For example, a control unit used with the AN/ARC-38 is designated C-1398/ARC-38. The letter C an indicator letter which in this case mea control. The number following C indicates t specific model of control box. Table 3-2 pr sents commonly used unit indicator letters th are used in the letter-number group.

Table 3-2.—Unit indicator letters.

Comp. ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
AB	Supports, Antenna	Antenna mounts, mast bases, mast sections, towers, e
AM	Amplifiers	Power, audio, interphone, radiofrequency, video, e
AS	Antenna Assemblies	Complex: Arrays, parabolic type, masthead, etc.
AT	Antenna	Simple: whip or telescopic, loop, dipole, reflector, al transducer, etc.
BA	Battery, primary type	B batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Signal Devices Audible	Buzzers, gongs, horns, etc.
C	Control Articles	Control box, remote tuning control, etc.
CA	Commutator Assemblies Sonar	Peculiar to sonar equipment.
CB	Capacitor Bank	Used as power supply.
CG	Cables and Transmission Lines	RF cables, waveguides, etc. with terminals.
CK	Crystal Kits	A kit of crystals with holders.
CM	Comparators	Analyzes or compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating regulat or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calc lating device.
CR	Crystals	Crystal in crystal holder.
CU	Coupling Devices	Impedance coupling devices, directional couplers, e

Table 3-2.—Unit indicator letters—Continued.

Comp. ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
CV	Converters (electronic)	Electronic apparatus for changing the phase or frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome nacelle, etc.
CX	Cords	Cord with terminals, also composite cables of RF and non-RF conductors.
CY	Cases	Rigid and semirigid structure for housing or carrying equipment.
DA	Antenna, Dummy	RF test loads.
DT	Detecting Heads	Magnetic pickup device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply.
E	Hoist Assembly	Sonar hoist assembly, etc.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FR	Frequency Measuring Devices	Frequency meters, echo boxes, etc.
G	Generators	Electrical power generators without prime movers. (See PU and PD.)
GO	Goniometers	Goniometers of all types.
H	Head, Hand and Chest Sets	Includes earphones.
HC	Crystal Holder	Crystal holder less crystal.
HD	Air Conditioning Apparatus	Heating, cooling, dehumidifying, pressure, vacuum devices.
ID	Indicating Devices	Calibrated dials and meters, indicating lights, etc. (See IP.)
IL	Insulators	Strain, stand-off, feed-through, etc.
IM	Intensity Measuring Devices	Includes SWR gear, field intensity and noise meters, etc.
IP	Indicators, Cathode-Ray Tube	Azimuth elevation, PPI panoramic, etc.
J	Junction Devices	Junction, jack, and terminal boxes: connectors, panels, etc.
KY	Keying Devices	Mechanical, electrical and electronic keys, coders, interrupters.
LS	Loudspeakers	Separately housed loudspeakers.
M	Microphones	Radio telephone, throat, hand, etc.
MD	Modulators	Device for varying amplitude, frequency, or both.
ME	Meters, Portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MK	Maintenance Kits or Equipment	Radio telephone general utility, etc.
ML	Meteorological Devices	Barometer, hygrometer, thermometer scales.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified. Do not use if better indicator is available.
O	Oscillators	Master frequency, blocking multivibrators, etc. (For test oscillators, see SG.)
OA	Operating Assemblies	Operating units associated together not otherwise covered.
OS	Oscilloscope Test	Test oscilloscopes for general test purposes.
PD	Prime Drivers	Gasoline engines, electric motors, diesel motors, etc.
PH	Photographic Articles	Camera, projector, sensitometer, etc.
PP	Power Supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PT	Plotting Equipments	Except meteorological boards, maps, plotting table, etc.
PU	Power Equipments	Rotating power equipment except dynamotors, motor-generator, etc.
R	Radio and Radar Receivers	Radio or radar receiver, composite receiver indicator, etc.
RD	Recorders and Reproducers	Tape and facsimile, disk, magnetic, etc.
RE	Relay Assemblies	Electrical, electronic, etc.
RF	Radiofrequency Component	Composite component of RF circuits. Do not use if better indicator is available.
RG	Cables and Transmission Line, Bulk RF	RF cable, waveguide, etc. without terminal.

Table 3-2.—Unit indicator letters—Continued.

Comp. ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
RL	Reel Assemblies	Antenna, field wire, etc.
RR	Reflectors	Target confusion, etc. Except antenna reflectors (See AT.)
RT	Receiver and Transmitter	Radio and radar transceivers, composite transmitter and receiver, etc.
SA	Switching Devices	Manual, impact, motor driven, pressure-operated.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SG	Generators, Signal	Includes test oscillators and noise generators. (See O.)
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
T	Radio and Radar Transmitters.	Communications, range, marker beacon, interrogator, composite transmitter-modulator, sonar drivers, etc.
TA	Telephone Apparatus	Miscellaneous telephone equipment.
TD	Timing Devices	Mechanical and electronic timing devices, range device, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning Devices	Tilt and/or train assemblies.
TK	Tool Kits or Equipments	Miscellaneous tool assemblies.
TL	Tools	All types except line construction.
TN	Tuning Units	Receiver transmitter, antenna, etc.
TS	Test Equipment	Test and measuring equipment including multipurpose testing devices not otherwise included.
TT	Teletypewriter and Facsimile Apparatus	Miscellaneous tape, teletype, facsimile.
TV	Tester, Tube	Vacuum-tube tester.
U	Connectors, Audio and Power	Unions, plugs, sockets, adapters, etc.
UG	Connectors, RF	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles	Carts, dollies, trucks, trailers, etc.
VS	Signaling Equipment, Visual	Flag sets, aerial panels, signal lamp equipment.
WD	Cables, Two Conductor	Includes non-RF wire, cable, and cordage in bulk.
WF	Cables, Four Conductor	Includes non-RF wire, cable, and cordage in bulk.
WM	Cables, Multiple Conductor	Includes non-RF wire, cable, and cordage in bulk.
WS	Cables, Single Conductor	Includes non-RF wire, cable, and cordage in bulk.
WT	Cables, Three Conductor	Includes non-RF cable, and cordage in bulk.
ZM	Impedance Measuring Devices.	Used for measuring Q, C, L, R, or PF, etc.

QUIZ

1. Electronic Material Changes that are made should be noted on the ________________ for the particular piece of equipment.

2. The Bureau of Aeronautics will issue new permanent instructions of an administrative nature concerning electronic equipment by
   a. a Bureau of Aeronautics Instruction
   b. a Bureau of Aeronautics Notice
   c. an Aviation Circular Letter
   d. the U. S. Naval Aviation Electronics Digest

3. Who should prepare the rough copy of an Electronic Failure Report?
   a. The technician making the repair
   b. A person who has been designated to fill out all failure reports in the shop
   c. The shop chief
   d. The electronics division officer

4. In the designation AN/ARC-27 the "AN" indicates ________________.

5. Normally, the four handbooks prepared for each model of equipment are ____________, ____________, ____________, and ____________.

6. Diagrams in the HSI are found in part
   a. IV
   b. V
   c. VI
   d. VII

7. Mandatory instructions for the maintenance of avionic equipment will be disseminated as a/an
   a. Electronics Material Bulletin
   b. Electronics Material Change
   c. Technical Order
   d. Aircraft Service Change

8. The failure of an exchangeable electronic component will be reported on a/an
   a. Electronic Failure Report (EFR)
   b. Failure, Unsatisfactory, or Removal Report, multiple set
   c. Request for Issue or Turn-in (DD 1150A)
   d. single-copy Failure, Unsatisfactory or Removal Report

9. The Naval Aeronautic Publications Index consists of
   a. 1 part
   b. 2 parts
   c. 3 parts
   d. 4 parts

10. Routine adjustments for a particular set of electronic equipment may be found in the ________________.

11. In the designation AN/ARC-27 the "A" following the slant means ____________.

12. Which publications are not assigned consecutive numbers?
    a. Instructions
    b. ECM
    c. EMB
    d. Notices

13. The instructions for the installation of electronic equipment in a specific aircraft type will be disseminated by
    a. Electronics Material Bulletin (EMB)
    b. Electronics Material Change (EMC)
    c. Service Change for the particular aircraft
    d. Handbook of Service Instructions for the equipment to be installed

14. The Handbook of Service Instructions usually contains which of the following number of sections?
    a. 4
    b. 5
    c. 6
    d. 7

15. Electronic Material Changes are issued by
    a. BuAer
    b. CNO
    c. ASO
    d. SecNav

16. Instructions for ordering publications are given in the front of part __________ of the Naval Aeronautic Publications Index.

17. In the designation AN/ARC-27 the "R" indicates ________________.

18. The three classes of Service Changes are ______________, ________________, and ______________.

19. The initials NAESU stand for __________ ______________.

20. In the designation AN/ARC-27 the "C" indicates ________________.

21. An aircraft service change with an "Immediate Action" classification must be incorporated
    a. prior to further flight of the aircraft
    b. not later than the next intermediate inspection
    c. at the next overhaul of the aircraft
    d. at the next major inspection

22. Electronics maintenance shops use a ____ for keeping a record of the work performed by the technician.

23. The two types of directives under the Navy Directives System are _____________ and ______________.

24. In the designation AN/ARC-27 the "27" indicates _________________.

25. The two reports that are used to determine material reliability are the ___________ ____________ and ___________________.

CHAPTER 4

TRANSISTORS AND MAGNETIC AMPLIFIERS

Transistors

The recent advent of the transistor in the field of electronics has as much significance and importance as the development of the vacuum tube in the early days of radio. The transistor proves that amplification, accomplished before mainly by vacuum tubes, can take place in a solid. This device has opened a new field of experiment and study in "solid-state" physics.

Two scientists, John Bardeen and W. H. Bratten, working under William Shockley of Bell Telephone Laboratories, developed the transistor (point-contact type) in 1948. Later (1949), Bell Telephone Laboratories announced that William Shockley had developed a junction transistor. Since then, transistors have been developed into practical and dependable electronic devices and the field of electronics has rapidly expanded the use of these "solid-state" devices.

To a comparable electron tube the transistor has a higher operating efficiency and is much smaller in size. One of the transistor's greatest advantages is that it has no filament, and, therefore, it needs no filament power supply. In the operation of the electron tube, over one-half of the power needed to operate the tube is filament power. In electronic equipments using transistors there will be a considerable reduction in size and weight because filament supplies are not needed. Since there is low power consumption in the transistor, there will be less heat radiation, allowing still more compact equipment to be designed. Another fact is that the transistor is ready to operate instantly at the application of operating voltage because the transistor does not require preheating.

Because the transistor is a solid, it can withstand the force of acceleration and deceleration many times that of the force of gravity.

Many new circuit ideas have been developed from the use of the transistor, but its full capabilities are not yet realized. At the present time there are many types of transistors in use. Many types of transistors are being developed; so, at any time you may find that some job previously done by a vacuum tube is being done better by a transistor.

Transistors are being utilized in more and more new electronic equipments; therefore, it is very important that you, as the technician, know how the transistor works. This first portion of the chapter will present the fundamental properties and operating principles of transistors.

If you are not familiar with the basic theories of atomic structure, it is suggested that you review chapter 1 of *Basic Electricity*, NavPers 10086, before continuing your study of transistors.

SEMICONDUCTORS

A semiconductor is a solid material that has a greater amount of conductivity than an insulator and less conductivity than a conductor. Some semiconductors are compounds,

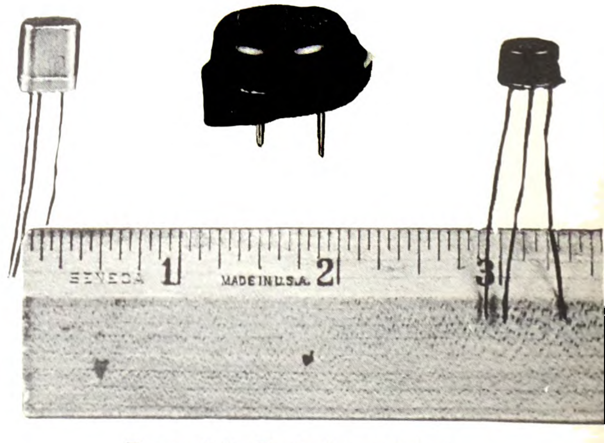


Figure 4-1.—Typical transistors.

such as copper oxide, zinc oxide, indium antimonide, gallium arsenide, and silicon carbide, while other semiconductors are elements, such as germanium and silicon. Silicon and germanium, when combined with certain impurities, are still classed as semiconductors. There are other materials that exhibit semiconductor properties, but since germanium and silicon are used extensively in the manufacture of transistors, the theory presented here will deal only with these two materials.

Figure 4-2 shows the resistive relationships of various insulators, semiconductors, and conductors. Note the resistive relationships between intrinsic silicon (pure silicon), intrinsic germanium (pure germanium), TRANSISTOR germanium, and impure germanium.

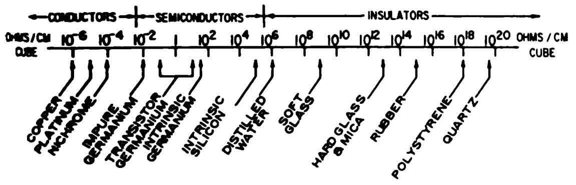


Figure 4-2.—Resistivity chart of common conductors, semiconductors, and insulators at 68° F.

Atomic Structure of Germanium and Silicon

At atom of germanium has 32 electrons distributed in 4 rings about its nucleus while the atom of silicon has 14 electrons distributed in 3 rings about its nucleus. (See fig. 4-3.) The inner rings of these elements (1st, 2nd, and 3rd rings of germanium and 1st and 2nd rings of silicon) are said to be COMPLETE and will not accept any more electrons. Electrons may be removed from the rings, but considerable energy would be needed to do so. This leaves only the outer electron ring of the atoms to be considered.

The outer ring of any atom determines the electrical and chemical characteristics of that atom. The core (inner rings and nucleus) of the atom is considered to be completely inactive. The electrons in the outer ring of an atom are called VALENCE electrons. To classify elements according to their electrical and chemical characteristics, they are placed into categories. One of these categories classifies the elements according to the number of valence electrons present in their atoms. The atoms of germanium and silicon are classified

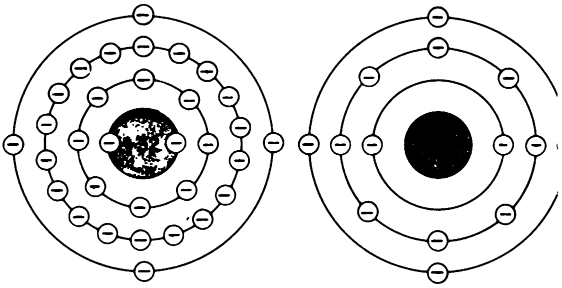

(A)
(B)

Figure 4-3.—Plan view of (A) the germanium atom and
the silicon atom.

as TETRAVALENT because they each ha
four valence electrons.

When one or more electrons are remov
from an atom or added to an atom, the at
is no longer electrically neutral in charge.
neutral atom of silicon, for example, has
protons in its nucleus and 14 electrons in
rings. If this silicon atom loses one of
valence electrons, it becomes a POSITI
ION with a net charge of +1 (14 protons a
13 electrons). However, should the silic
atom take on an electron, it will become
NEGATIVE ION with a net charge of -1 (14 pr
tons and 15 electrons). (NOTE: The addi
of electrons to electrically neutral atoms
usually confined to chemical activity.)

An application of energy is necessary
remove an electron from an atom. The for
of energy commonly used in electronics a
(1) electric fields (e.m.f. that causes electr
flow in a conductor), (2) heat (cathode of
vacuum tube), (3) light (photoelectric cel
and (4) bombardment by other particles (th
ratron operation). The amount of energy need
to move an electron from the atoms of diffe
ent elements varies with the elements. F
example, more energy is needed to remove
electron from the silicon atom than is need
to remove an electron from the germaniu
atom.

Crystal Structure of Germanium and Silic

In their pure solid state, intrinsic ge
manium and silicon are crystals in the sha
of cubes. Each of the four valence electro
of an atom form bonds with an electron fr
one of the four nearest atoms. These bon
of paired electrons, called COVALENT bon
provide the force that binds the atoms togeth

to form the crystal structure. Any crystal is a regular array of atoms; and in the case of germanium and silicon, this regular array of atoms forms a tetrahedral crystal. Figure 4-4 shows a three-dimensional crystal structure of germanium and silicon. The rods connecting the atoms represent the covalent bonds between the atoms.

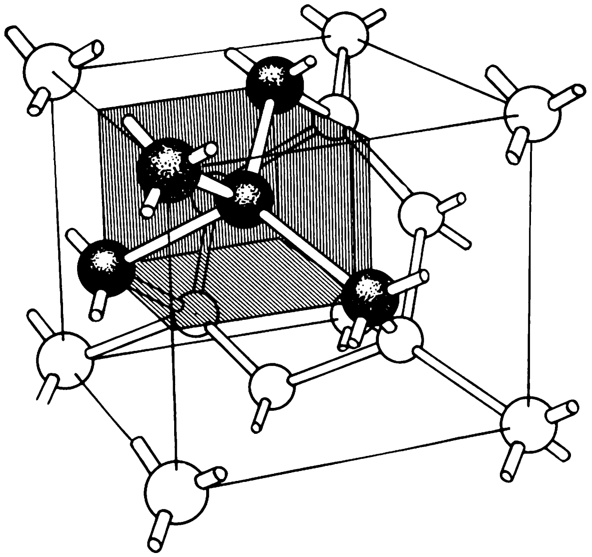


Figure 4-4.—Tetrahedral crystal structure of germanium and silicon.

The tetrahedral structure of figure 4-4 is redrawn in a two-dimensional form (plan view) in figure 4-5. Figure 4-5 (A) shows the germanium crystal and figure 4-5 (B) shows the silicon crystal. Note that all atoms are equidistant from each other and that between the cores of any two atoms there are two valence electrons.

In the crystal structure of intrinsic germanium and silicon, the forces of attraction and repulsion between atoms and electrons balance each other. Due to thermal agitation at ordinary room temperatures (68° F.), some electrons gain sufficient energy to break their covalent bonds and become free. These free electrons will allow some conduction (current flow) when an e.m.f. is impressed across the crystal.

HOLE AND ELECTRON FLOW

When an electron breaks away from its covalent bond and becomes free, it leaves an

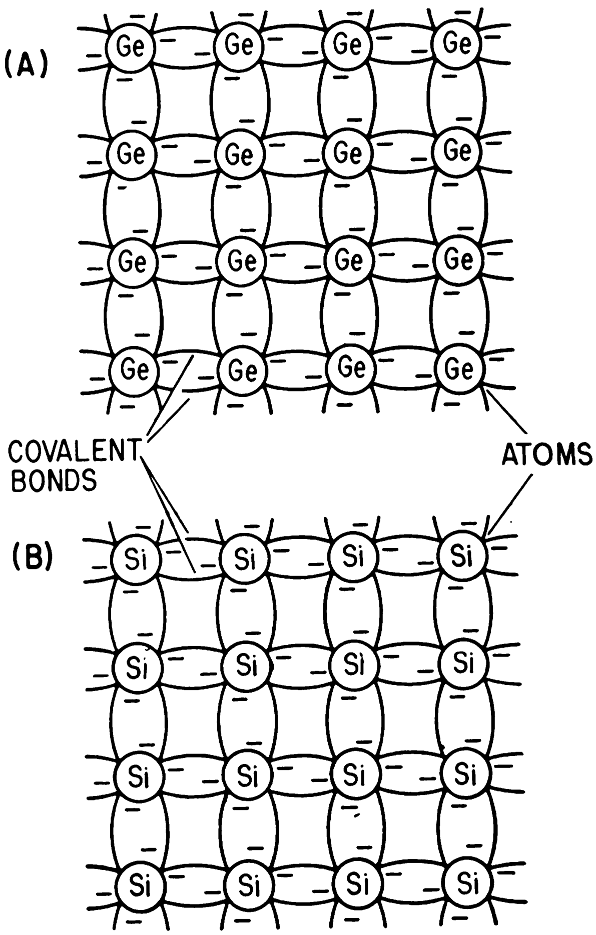


Figure 4-5.—Two-dimensional view of (A) the germani
crystal and (B) the silicon crystal.

empty space called a HOLE. If a nearby ele
tron becomes free from its covalent bond b
thermal agitation, it will jump into this wai
ing hole. (NOTE: This is because electro
in a crystal structure always seek to arrang
themselves in covalent pairs.) The hole th
electron filled is not destroyed but has mere
moved to the point that the electron left.
effect then, the hole, which acts as a positi
charge, has moved and will keep on moving
long as an adjacent covalent electron is free
The action of this hole is the same as the fr
electron in that it moves about in an irregul
manner. In a crystal there are many su
negative electron and positive hole combin
tions taking place at one time. At the sa
time, the energy (whether light, hear, or
electric field) being supplied to the crys
will constantly be breaking other bonds. Eve
tually there will be as many covalent bon
being broken as there are being reformed.

If the energy supplied to a crystal of a semiconductor is an electric field developed by the application of an e.m.f. across this crystal, the random movement of the electrons and the holes will be less, and they will be directed along the lines determined by the e.m.f. The electrons will move toward the positive terminal while the holes will drift toward the negative terminal. The action of the hole and electron flow is additive and represents the total current flow through the crystal.

The hole and electron flow theory presented here deals with intrinsic germanium and silicon. In normal temperature these materials have very few electrons and holes. Large numbers of electrons and holes are needed to obtain transistor action. These are obtained by adding impurities to the semiconductor material. The amount of impurities added to the semiconductor materials are carefully controlled.

There are two types of materials produced by the addition of impurities to silicon or germanium. These materials are known as *N*-type and *P*-type semiconductors.

N-TYPE SEMICONDUCTOR MATERIAL

If an impurity such as arsenic is mixed with germanium or silicon, many free electrons will be produced. This is because the atom of arsenic is pentavalent (has five valence electrons); and when introduced into germanium or silicon in very small amounts (one part in one million), displaces some atoms of germanium or silicon and forms four covalent bonds by using four of its valence electrons. (See fig. 4-6 (A).) The extra electron has no adjacent electron with which to form a covalent bond; thus it is free to move within the crystal. A semiconductor with excess electrons, such as germanium with arsenic, is called an *N*-type semiconductor material because its CURRENT CARRIERS are electrons. The impurities that produce many free electrons in germanium or silicon are called doNors. Some other impurities that can be used as donors are phosphorous and antimony.

P-TYPE SEMICONDUCTOR MATERIAL

By adding impurities that have three valence electrons (trivalent) instead of five, a semiconductor will be produced that has an excess of holes. Boron, gallium, and indium are examples of such substances used as impurities.

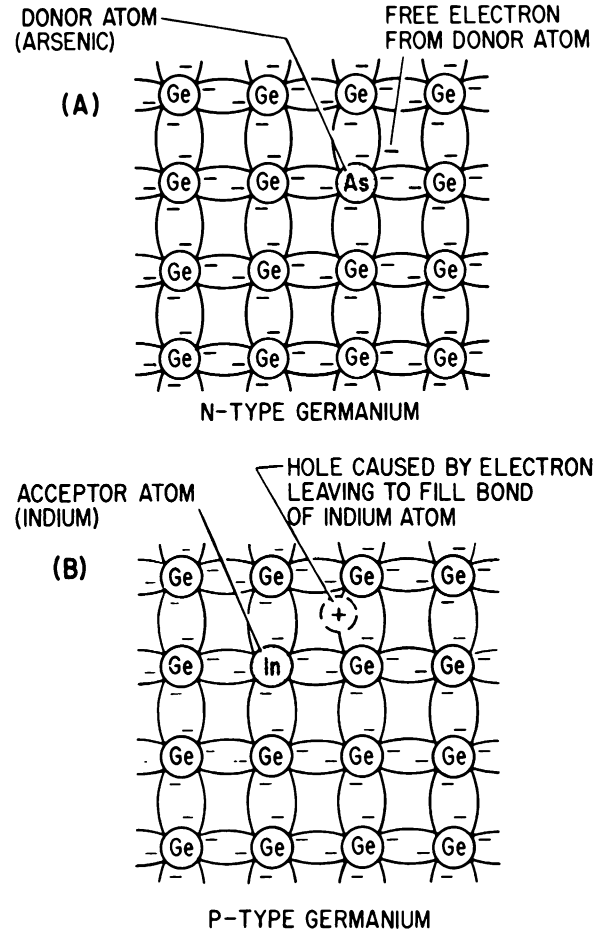


Figure 4-6.—(A) Germanium with a donor atom; (B) germanium with an acceptor atom.

Each trivalent impurity atom will replace a germanium or silicon atom in the crystal structure. (See fig. 4-6 (B).) There is now a deficiency of one electron; and in order to complete the four covalent bonds, the trivalent atom attracts an electron from a nearby germanium or silicon bond. This results in a hole being left in the adjacent covalent bond. When a very small amount (one part in one million) of trivalent impurities, called accePtors, are added to intrinsic germanium or silicon a series of holes are produced and the material is called a *P*-type semiconductor.

When an e.m.f. is applied across a *P*-type semiconductor crystal, the holes move toward the negative potential or terminal. This is brought about by a hole attracting an electron from a nearby covalent bond. When this electron leaves a covalent bond, the bond is broken leaving a hole. In effect then, the hole has moved from one position to another. This movement or drift of the hole continues on through the material and towards the negative field or potential.

As the holes reach the negative terminal, they are filled in by electrons flowing from this terminal. At the positive terminal an equal number of holes is created by electrons being pulled into the positive terminal. The crystal is now conducting current, and this current is considered to be a flow of holes from the positive to the negative terminal.

In the following explanations of semiconductor diodes and transistors, only the germanium types will be discussed. (NOTE: Silicon types of diodes and transistors could just as well be used in this discussion since the same theories of operation pertain to both germanium and silicon materials.)

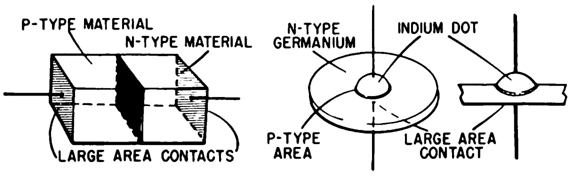
SEMICONDUCTOR DIODES

PN Junctions

When *N*-type germanium and *P*-type germanium are combined, as shown in figure 4-7, a germanium JUNCTION diode is formed. To combine *N*-type to *P*-type germanium does not mean that two materials are mechanically fitted together. To make a satisfactory junction, a single crystal must be formed with both *P*-type and *N*-type characteristics. There are two methods of combining the two types of material; these are known as the FUSED junction and the GROWN junction methods.

A grown junction (fig. 4-7 (A)) is formed by growing a single crystal from a melt. At the start the melt contains donor impurities and *N*-type material is formed. In the middle of this forming process, acceptor impurities are added to form the *P*-type portion of the crystal.

The fused (or alloy) junction diode (fig. 4-7 (B)) is formed by placing a small amount of indium on a slab of *N*-type germanium. This combination is then heated to a specific temperature for a certain amount of time so tha the indium fuses to the germanium. Thi fusion produces a *P*-type area of germaniun in the slab immediately below the indium dot



(A) GROWN JUNCTION DIODE (B) FUSED JUNCTION DIODE

Figure 4-7.—Junction diodes: (A) Grown; (B) fused.

Operation of PN Junction Diode

When there is no voltage applied to th *PN* junction diode, there is a deficiency c electrons and holes at the junction of the *P* type and *N*-type material. This is becaus the electrons and holes in this junction are have combined. It might seem that the combining of holes and electrons would continu until there were no longer any holes or electrons left. However, this is not the cas After the initial combining of holes and electrons at the junction, a potential barrier produced. Figure 4-8 illustrates the formatic of the barrier.

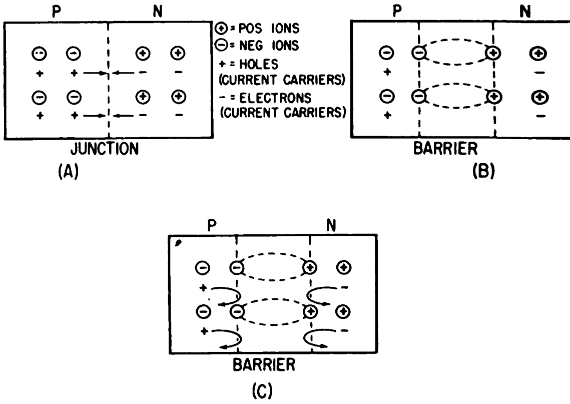


Figure 4-8.—PN junction formation of barrier by ions

After the combining of the holes and ele trons (fig. 4-8 (A)), positive and negative ic will be uncovered (fig. 4-8 (B)). An electri field is set up at the junction of the *P* anc material because of these ions. (NOTE: better understand how the positive and neg tive ions are produced refer to figure 4-6. the (A) portion of this figure a donar atom arsenic is changed into a positive ion when free electron is moved away from this ar Likewise, in part (B) the acceptor atom indium is changed to a negative ion when hole is moved away from this area.) positive ions at the barrier will repel the hc in the *P* material, while the negative ions repel the electrons in the *N* material (fig. (C)). It may be noted here that the ac barrier developed is only a few centimeters thick. This thickness determines the barrier level or barrier potential.

In order to produce a flow of current across the barrier, the barrier's electrical field or potential must be neutralized. This can be done by applying an external potential across the ends of the *PN* diode. (See fig. 4-9 (A).) The negative terminal of the battery is connected to the *N* side of the diode while the positive terminal is connected to the *P* side. This particular connection to the diode is called the FORWARD BIAS connection. The free electrons in the *N* section are repelled by the applied negative field and they will move toward the *PN* junction. At the same time, the holes in the *P* section are repelled from the positive field, forcing them toward the junction. If this applied potential is large enough, it will overcome the barrier potential and enable the holes and electrons to move to the opposite sides of the barrier. As the barrier crossing is made, the electrons and holes will combine, allowing current to flow through the *PN* diode. (NOTE: New holes are produced at the positive terminal by the electron removal and at the same time electrons are introduced into the *N* material from the negative terminal.)

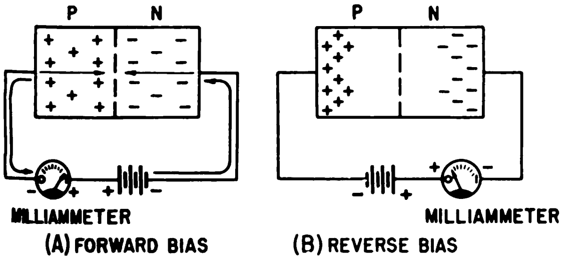


Figure 4-9.—Forward bias and reverse bias applied to the PN junction.

In the preceding explanation the *PN* junction iode was biased in the forward or low resisnce direction. When the polarity of the applied oltage is reversed, the diode will be biased in e high resistance direction or it will have hat is called REVERSE BIAS applied to it. ee fig. 4-9 (B).) This reverse bias actually creases the potential barrier that is present the *PN* junction. The positive terminal that connected to the *N* side of the diode will atact the electrons (current carriers) in the material. Likewise, the negative terminal will attract the holes in the *P* material. I to these conditions, holes and electrons can combine with each other, resulting in onl minute amount of current flowing in the dio This small amount of current is caused by c rent carriers called minority carriers. Th minority carriers are electrons and hol resulting mainly from thermal agitation, are located on the wrong side of the juncti that is, holes are located in the *N* material electrons are located in the *P* material. I to the locations of these minority current c riers, they are not in opposition to the appl potential and will therefore move across junction, causing some current flow.

Point-Contact Diodes

Figure 4-10 (A) shows a cutaway view o point-contact diode. The theory of operat of the point-contact diode is the same as theory of operation of the *PN* junction dio The difference between the two diodes their physical construction and use.

The construction of the point-contact di usually begins with a small square of *N*-ty germanium with a phosphor-bronze or ber lium-copper "cat whisker" pressed agai the center of one side of the crystal. A me plate is connected to the other side of crystal face. This plate provides electri contact to the *N* side of the crystal.

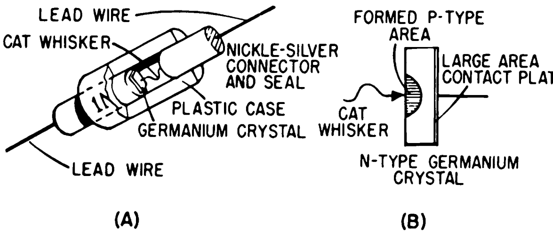


Figure 4-10.—(A) Cutaway view of a point-contact dio (B) point-contact diode showing P-type area in the N material.

The actual diode is formed by passing a lar amount of current from the "cat whisker" the *N*-type germanium slab. The result of th current flow is that a small area of *P*-type ge manium is formed in the region surrounding t contact area of the "cat whisker" (fig. 4- (B)). The point-contact diode now consists both *P*-type and *N*-type germanium.

Semiconductor Diode Applications

Semiconductor diodes are being used to do many jobs in the field of electronics that were previously done by other types of rectifiers. Junction diodes of silicon and germanium may be used in high power applications (hundreds of amperes) as well as low power applications (millamperes). Point-contact diodes are usually used as low power rectifiers, detectors, mixers, clampers, clippers, and so forth. Both junction and point-contact diodes are very efficient and compact as compared to other types of rectifiers.

Figure 4-11 (A) shows the symbol used for semiconductor diodes. Electron and current flow is against the arrow. (NOTE: There are two theories on electron and current flow. One is that current flows in the opposite direction of electron flow. The other theory and the one accepted by the Navy is that electron flow and current flow are in the same direction.) In the symbol used for semiconductor diodes, electron flow is against the arrow, therefore, it must be accepted that current flows in this same direction.

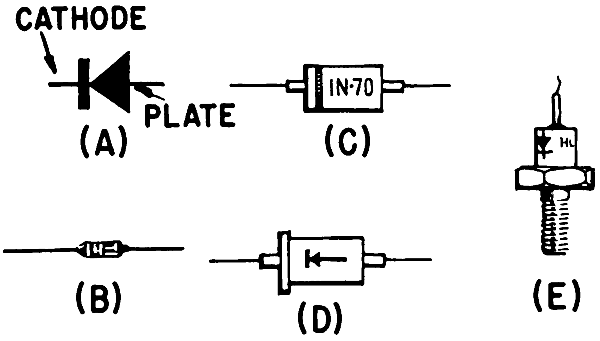


Figure 4-11.—(A) Symbol for semi-conductor diodes; (B), (C), (D), and (E) typical diodes, actual size.

Comparing the semiconductor diode to a vacuum-tube diode, the straight bar of the symbol is considered the cathode (*N* material), while the arrow represents the plate (*P* material.)

Figure 4-11 (B), (C), (D), and (E) shows some typical semiconductor diodes; these are shown in actual size. These drawings also show different methods that are used to identify the cathode connection. In (B) and (C) of figure 4-11 the end marking band is nearest the cathode end, while in (D) and (E) the cathode is indicated by the semiconductor symbol.

Care and installation of semiconducto diodes is discussed in chapter 8 of this trai ing course.

TRANSISTOR THEORY

At present, there are many different typ of transistors in use and many other types the developmental stage. Some of the tra sistors that are in use are the point conta junction, drift, tetrode, unijunction dynisto and surface barrier. Each has its own uniq characteristics, advantages, and areas of a plication.

Since the junction transistor (*PNP* a *NPN*) is the most commonly used, its theo of operation will be thoroughly discussed.

There are two basic types of junction tra sistors, the *NPN* and *PNP*. Since there is difference in direction of current flow and r quired voltage polarity in these two types junction transistors, they will be discuss separately.

NPN Junction Transistor

The *NPN* junction transistor (fig. 4-12) actually a *PN* junction with another sectio *N*-type material formed to the *P* section of junction. There are three main methods u in forming the junction transistors: the gr junction (usually *NPN*), the fused (or all junction (usually *PNP*), and diffusion (*PNP* *NPN*).

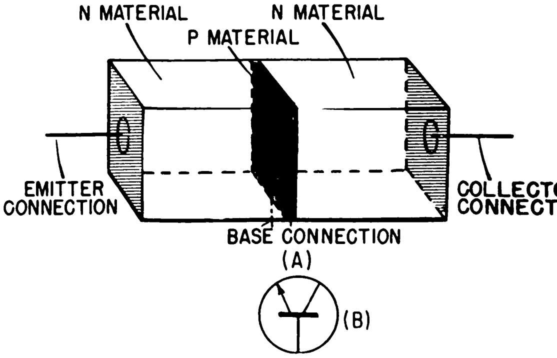


Figure 4-12. —NPN transistor, grown-junction typ

The junction transistor is composed of t sections, the EMITTER, the BASE, and COLLECTOR. (See fig. 4-12.) The emi emits current carriers into the base regio the transistor; the collector collects mo these current carriers from the base reg The base is a common point for biasing collector and emitter. In the *NPN* transistor the emitter and collector are made of *N*-type material and the base is made of *P*-type material.

The forward bias is applied between the base and emitter (negative polarity connected to the emitter and positive polarity to the base). As will be seen later, this emitter bias will control the amount of current through the transistor. Figure 4-13 (A) shows the *NPN* transistor with only emitter bias connected to it. Notice that the direction of current flow (I_e) is the same as in the *PN* junction diode with forward bias. The electrons in the *N* material and the holes in the *P* material will combine at the junction to cause current to flow from the negative potential to the positive potential of the bias supply.

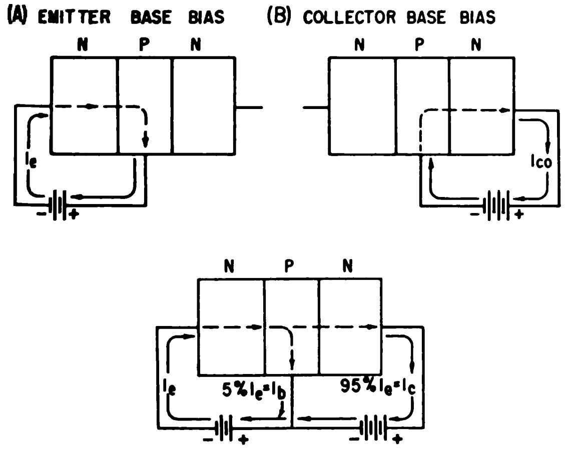


Figure 4- 13. —Bias applications to an NPN transistor.

Reverse bias is applied between the base and collector (negative polarity connected to the base and positive polarity connected to the collector). Figure 4-13 (B) illustrates the reverse bias connection to the *NPN* transistor. Under this condition with only reverse bias applied, the collector current (I_c) will be zero. There is, however, a current flow called I_{co}, flowing in the collector circuit. As in the *PN* unction with reverse bias, this current is aused by minority carriers. I_{co} designates llector current when there is NO emitter rrent.

Figure 4-13 (C) shows both biases connected. st of the emitter current (I_e) flows through base to the collector material. This current ws in the collector and becomes collector rrent (I_c). The current (electrons) flows through the base because of two reasons. First, the base is very thin (0.001 inch); and second, the positive attracting force of the collector potential impels the electrons through the base.

In figure 4-13 (C) it can be seen that the emitter and collector bias batteries are connected in series-aiding so that the circuit for electron flow from the emitter through the base and to the collector is complete. Probably no more than 5 percent of the emitter electrons combine with the holes in the base. The remaining emitter electron flow (95 percent) passes through the base into the collector material.

The number of electrons leaving the emitter depends entirely on the emitter-base bias. This current is varied by changing the emitter-bias voltage. Since the base current is very small, a change in emitter bias will have a far greater effect on the emitter-collector current than on the base current. (NOTE: The collector can be compared to the plate of an electron tube, the emitter can be compared to to the cathode, and the base compared to the grid.)

The transistor's ability to amplify lies in the fact that there is a difference in the emitter-to-base resistance ($r_e + r_b$) and collector-to-base resistance ($r_c + r_b$). The emitter resistance is very low (500 ohms), because it is biased in the forward or low resistance direction. The collector resistance is extremely high (500,000 ohms), because it is biased in the high resistance or reverse direction.

Since collector current is 95 percent of emitter current, this gives the junction transistor a current gain of 0.95. (NOTE: Current gain is designated ALPHA and is figured by dividing collector current (I_c) by emitter current (I_e).) Using the current gain and the emitter and collector resistances, the approximate voltage and power gains of the junction transistor can be shown. If ALPHA (α) = 0.95, $r_e + r_b = 500$ ohms, and $r_c + r_b = 500{,}000$ ohms then

$$\text{Voltage gain} = \alpha \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Voltage gain} = 0.95 \times \frac{500{,}000 \text{ ohms}}{500 \text{ ohms}}$$

$$\text{Voltage gain} = 0.95 \times 1{,}000$$

$$\text{Voltage gain} = 950$$

Using the above values of ALPHA, emitter-base resistance, collector-base resistance, and the power formula $P = I^2R$, the power gain can be shown.

$$\text{Power gain} = \frac{\text{Power out}}{\text{Power in}}$$

$$\text{Power gain} = \alpha^2 \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Power gain} = 0.95^2 \times \frac{500{,}000 \text{ ohms}}{500 \text{ ohms}}$$

$$\text{Power gain} = 0.9025 \times 1{,}000$$

$$\text{Power gain} = 902.5$$

Although the junction transistor can never have a current gain greater than one, the above examples show that the transistor is capable of producing voltage and power gains. The reasons these gains are obtainable is because of the high collector resistance and the low emitter resistance.

Figure 4-14 shows an *NPN* transistor connected as an amplifier. An a-c signal source is connected in series with the base bias (B_1) and the emitter; a load resistor (R_L) is connected in series with the collector bias (B_2) and the collector.

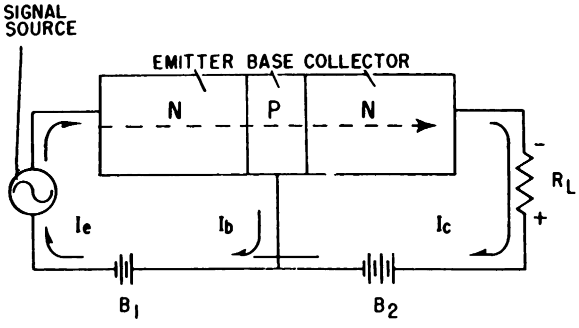


Figure 4-14.—NPN transistor connected as an amplifier.

With zero applied signal, the emitter and collector currents are dependent on the emitter-base bias. If the applied signal goes negative, it increases the forward bias which increases emitter current. This increase in emitter current causes an increase in collector current which, in turn, causes a greater drop across R_L. When the signal at the emitter goes positive, the emitter-base bias decreases, causing a decrease in emitter current, a decrease in collector current, anc therefore a decrease in the voltage drop acros (*R*$_L$). In figure 4-14, signal amplification is obtained, but there is no signal phase shift o inversion between input and output. Later i will be seen that there are other methods o connecting a transistor in which there will b a signal phase shift (or inversion).

Since transistors are an entirely new approach to a means of amplification, with man new features and characteristics, it may caus some confusion to the technician who tries t compare the transistor with the vacuum tub point by point. A better understanding wi result if you learn the operation of transis tors by using only the terms and ideas that ar common to transistors.

PNP Junction Transistor

The *PNP* transistor uses *P*-type materi for the emitter and collector and *N*-type ma terial for the base. Most *PNP* transistors a of the fused junction type.

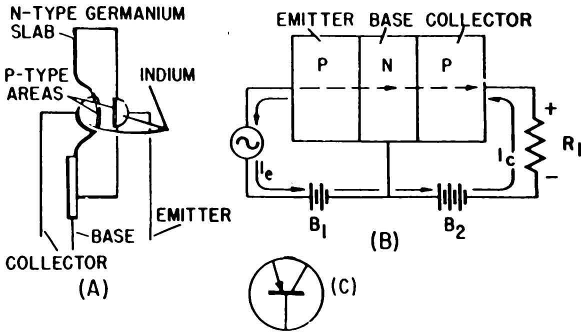


Figure 4-15.—(A) PNP junction transistor, fused juncti (B) bias connections to the PNP junction transis (C) transistor symbol.

As in the *NPN* transistor, forward bias applied between the base and emitter and verse bias applied between the base and c lector (fig. 4-15 (B)). Since the emitter, ba and collector are made of opposite type n terials to that used in the *NPN* transistor, bias polarities are reversed. With the emit and collector made of *P*-type material, the c rent carriers in the transistor will be hol As in the *PN* junction diode, the current f in the connecting wires consists of electr

The operation of the *PNP* transistor is same as the *NPN* except the current flow i the opposite direction. For example, in fig 4-15 (B) if a positive-going signal is app to the emitter, it will add to the forward bias (B_1), causing an increase in I_e. This will increase hole flow to the collector, causing an increase in I_c and an increased voltage drop across R_L. (NOTE: I_c is normally referred to as negative current in the *PNP* transistor. The reason for this is to distinguish between *NPN* collector current and *PNP* collector current.) If the signal applied to the emitter is negative going, it will subtract from the emitter bias (B_1) and cause a decrease in emitter hole flow. Therefore, this will cause a decrease in I_c and a decrease in the voltage drop across R_L.

Point-Contact Transistor

The point-contact transistor is very similar to the junction transistor. The point contact was the first transistor developed; it is being replaced by the junction transistor. Most of the theory presented on the junction transistor will apply to the point contact.

The construction of a point-contact transistor is shown in figure 4-16 (A). In this transistor the emitter and collector connections are made through the pointed ends of very small electrodes. The points of these electrodes, which are spaced only a few thousandths of an inch apart, are connected to the base material. The base material may be either *P*-type or *N*-type germanium crystal. (NOTE: *N*-type material is the only material used to construct point-contact transistors that are used commercially.)

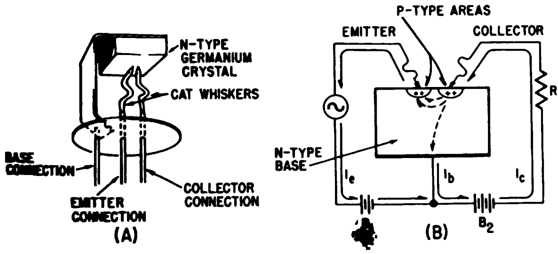


Figure 4-16.—(A) Point-contact transistor; (B) point-contact transistor with bias voltage applied.

The *P*-type area for the emitter and collector is formed by passing a controlled amount of current from the emitter and collector wires to the base. The area formed in the *N*-type material, by this method is very small. With an emitter of *P*-type material, a base of *N*-type material, and a collector of *P*-type material, a transistor is produced whose theory of operation is similar to the theory used in the explanation of the junction transistor.

Referring to figure 4-16 (B), it can be seen that the bias voltages are connected to the point-contact transistor with the same polarities used in the connection of the *PNP* junction type; that is forward bias from emitter to base and reverse bias from collector to base. With both of these biases applied there will be hole flow from the emitter through the base area into the *P* area of the collector (same as in the *PNP* transistor). Here the resemblance of operation between this point-contact transistor and the *PNP* junction transistor ends. In the junction transistor the collector current (I_c) would now be about 95 percent of the emitter current (I_e), but the collector current in the point-contact transistor measures anywhere from 2 to 3 times the emitter current. Thus, the point-contact transistor has an α (current gain) of around 2 to 3.

There is some doubt as to why the collector current is so much greater than emitter current. The theory presented on this point is very vague. It is generally believed that this additional current is caused by the moving holes forming a positive space charge in the base-to-collector area. The result of this space charge is to attract other electrons from the relatively large base area (*N*-type material) and cause them to flow in the collector-to-base circuit. When this collector-to-base current is added to the normal collector current, the result is a total collector current (I_c) of 2 to 3 times more than emitter current (I_e).

A typical voltage gain of a point-contact transistor can be shown by the same method used to figure the typical junction transistor's gain. In a typical point-contact type the emitter-to-base resistance ($r_e + r_b$) is around 250 ohms and the collector resistance ($r_e + r_b$) is around 25,000 ohms. Using these resistance values and an average ALPHA (α) of 2.5

Voltage gain =

$$\alpha \times \frac{r_c + r_b \text{ (resistance of collector)}}{r_e + r_b \text{ (resistance of emitter)}}$$

$$\text{Voltage gain} = 2.5 \times \frac{25{,}000 \text{ ohms}}{250 \text{ ohms}}$$

$$\text{Voltage gain} = 2.5 \times 100$$

$$\text{Voltage gain} = 250$$

Comparing this gain with the gain of a junction transistor (950), it can be seen that the junction transistor has considerably more gain. The reason for this is because of the high collector resistance (r_c) of the junction transistor, which gives it a higher resistance gain.

The point-contact transistor also has power gain. As in the junction transistor, this can be proven by using Ohm's law ($P = I^2R$).

$$\text{Power gain} = \frac{\text{Power out}}{\text{Power in}}$$

$$\text{Power gain} = \alpha^2 \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Power gain} = 2.5^2 \times \frac{20{,}000 \text{ ohms}}{250 \text{ ohms}}$$

$$\text{Power gain} = 6.25 \times 80$$

$$\text{Power gain} = 500$$

(NOTE: The formulas that have been used give only approximate gains; they have been used for the purpose of explaining the operation of the junction and the point-contact transistor.)

Tetrode Junction Transistor

The tetrode junction transistor, an *NPN* transistor with a fourth connection, was designed to extend the operating frequency range of the junction transistor.

In this transistor the fourth connection i made to the base material (fig. 4-17 (A)) opposite to the normal base connection. A bia potential is connected between this added connection and the normal base connection (fig 4-17 (B)). The potential, usually a negativ six volts, is fixed and will not vary with signa input or output. This negative bias voltage wil change the flow of current through the transistor by restricting the flow of electrons fro the emitter to the collector.

Since the field produced by the six volts i negative, it will repel or stop the flow o electrons from the emitter to the base along this junction except at a small area near th original base connection. The electrons ca move through this small area because the effect of the -6-volt field is so weak that th emitter-base bias overcomes this field. Thi may be more easily understood if the base are B_{A1} and B_{A2} is considered as a resistor (See fig. 4-17 (B).) With the -6 volts applied the voltage drop from B_{A1} and B_{A2} is progressively greater. An area will be reache near B_{A2} where the voltage drop is less tha the potential of the emitter-base bias (B_1 From this point to the base connection (B_{A2} electrons will flow from the emitter through th base and into the collector.

The tetrode gives better high-frequenc response because (1) the collector capacitanc is reduced by effectively reducing the electri cal size of the base, and (2) the base resistanc decreases because current flow is closer to th base connection.

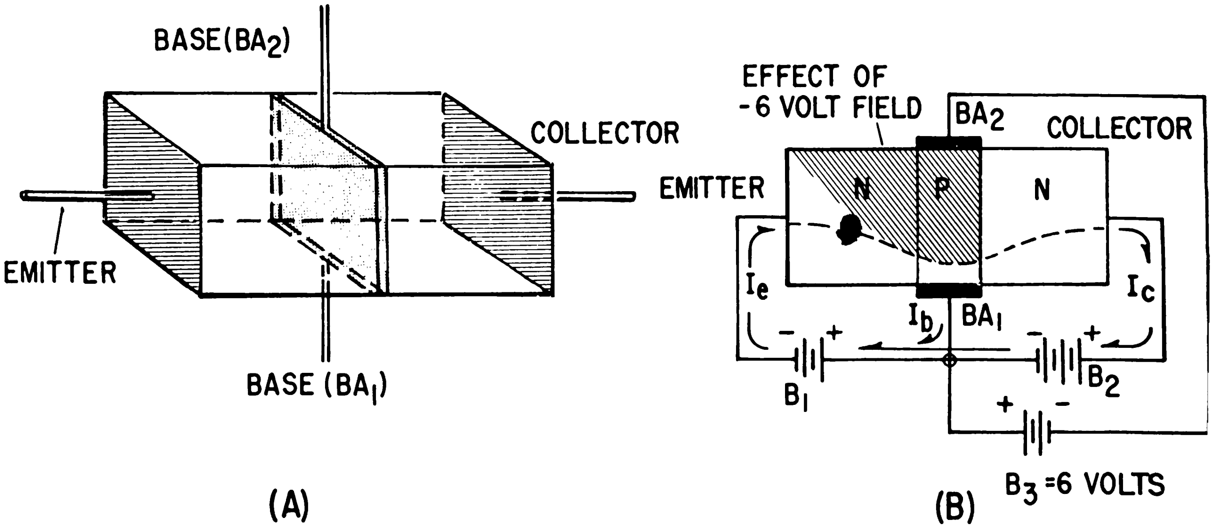


Figure 4-17.—(A) The tetrode transistor; (B) bias connections to the tetrode transistor.

Intrinsic Barrier Transistor

The intrinsic barrier transistor is another transistor design that is used to extend the high-frequency operating range of junction transistors.

Two types of intrinsic-barrier transistors are produced, the *NPIN* and the *PNIP*. These are junction transistors (*NPN* or *PNP*) with a layer of intrinsic germanium inserted between the base and collector. Figure 4-18 shows a *PNIP* intrinsic transistor.

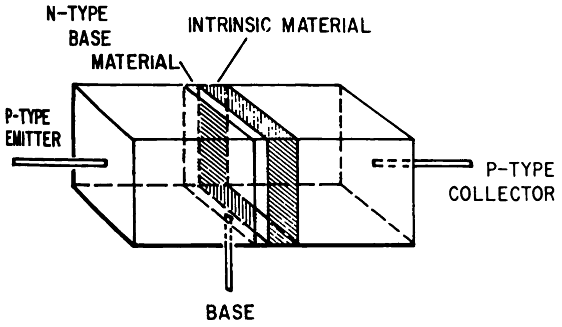


Figure 4-18.—PNIP intrinsic-barrier transistor.

The bias voltages applied to this type of transistor are applied in the same manner as in the junction types. There is no bias applied or external connection made to the intrinsic layer. In operation this device conducts current carriers the same as the *NPN* or *PNP* junction types. For example, in the *PNIP* type, holes leave the emitter, diffuse across the base, and then travel through the intrinsic area at a very high speed. (NOTE: Holes or electrons travel through the intrinsic region extremely fast because there are no donor nor acceptor ions to cause a barrier to be formed either at the base intrinsic material junction or at the intrinsic material collector junction.)

This intrinsic layer of germanium increases the upper frequency operating limits of junction transistors in several ways. One of the reasons is that the collector-to-base capacity is greatly decreased. This decrease occurs because the intrinsic layer now separates the base and collector. Another reason is that the separation produced by the intrinsic layer results in a higher collector-to-base breakdown voltage characteristic. This allows the base to be made much thinner. The thinner base results in a lower base resistance and therefore a higher frequency limit on the transistor.

Other Transistors

There are many other types of transistors. Some are in the developmental stage and others are already in use. It would be impractical to discuss all of the many different types in this training course. The foregoing explanations of the junction, point-contact, tetrode, and intrinsic-barrier transistors are sufficient for an adequate understanding of transistors.

TRANSISTOR CHARACTERISTICS

Frequency Response

There are several factors that affect the frequency response of both point-contact and junction transistors. One of the more important of these is the time it takes for a signal to travel from emitter to collector. This is similar to the transit time that is present in vacuum tubes. Since the signal is carried by current carriers, the speed of these current carriers will determine the time of signal travel. As compared to electron travel in a vacuum tube, electron travel in the transistor is very slow and hole travel is still slower. Because of this the *NPN* transistor can possess a higher frequency response than the *PNP*. This is true because in the *NPN* transistor the current carriers are electrons, while in the *PNP* transistor the current carriers are holes. Basically, the point-contact transistor has a somewhat higher frequency response than the junction type because the distances that signals have to travel from emitter to collector are very short. However, during the last few years many junction transistors have been manufactured with frequency responses exceeding those of the point-contact type.

Another important factor affecting high-frequency response is the capacity between the sections of the transistor. The potential-barrier field existing on each side of the base material results in input capacity (emitter-to-base and emitter-to-collector) and output capacity (collector-to-base and collector-to-emitter). The higher the applied frequency the greater the loss of signal, in both input and output of the transistor, because of a lowered capacitive reactance.

Cutoff Frequency

The frequency rating of a transistor is given as its ALPHA CUTOFF FREQUENCY. The symbol used for this rating is f_{aco} and may be stated in kilocycles or megacycles. The f_{aco} is determined by measuring a given transistor's ALPHA at 270 cycles and then raising the applied frequency until ALPHA drops to 70.7 percent (3 db) of the original value. The frequency indicated is f_{aco}.

Some of the newer type transistors, such as the tetrode, intrinsic barrier, and surface barrier, have a very high f_{aco}. For example, there is a manufactured tetrode transistor that has an f_{aco} of 250 megacycles.

Power Handling Capabilities

The point-contact transistor is a low-power device. Because of the small area between the emitter's and the collector's "cat whiskers," the amount of current handled is relatively small. The heat produced in this area limits point-contact power outputs to less than a watt.

Because of the low resistance contacts that can be made to the collector and emitter in the junction transistor, it can be designed to handle large amounts of power. Some types are produced that handle hundreds of watts of power. The power-type junction transistor is mounted in a hermetically sealed metal case. For better heat dissipation the case itself is usually the collector connection. The power transistor may be mounted on a metal chassis for greater power handling capability. This chassis serves as a "heat sink" and dissipates the heat by conduction; unless this heat is conducted away from the transistor, it will not operate properly. (See fig. 4-19.)

Temperature Considerations

Transistors are extremely sensitive to temperature variations. If a transistor's temperature rises excessively, many more free electrons and holes (broken covalent bonds) will be produced. Under actual operations this will cause the emitter current to lose control of the collector current. If this happens, the ability of the transistor to amplify is decreased. It is also possible for heat to cause greater collector current. This increase in collector current causes more heat to be produced, which, in turn, causes more collector current. This action is cumulative and results in the transistor being quickly destroyed. The operating temperature limits of a particular transistor, as specified by the manufacturer, must not be exceeded.

Noise

Generally speaking, transistors produce more noise than vacuum tubes produce. Some of the noise they produce is similar to the nois produced in resistors and in vacuum tubes Noise is produced by the movement of the cur- rent carriers through the junctions and also b

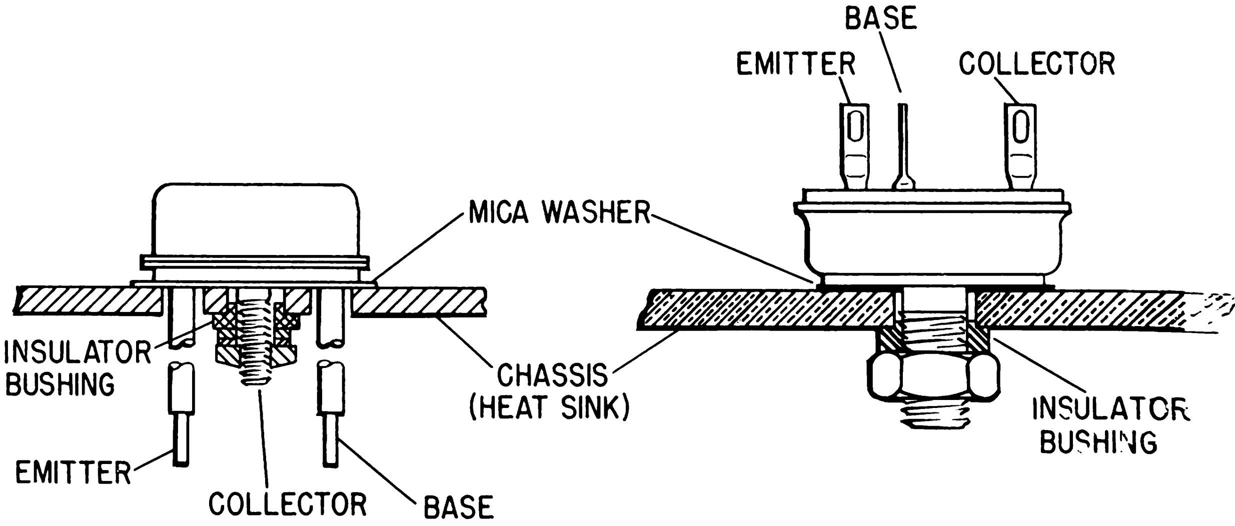


Figure 4-19.—Chassis mounted power transistors.

the random division of emitter current carriers between the base and collector. The noise figures of junction transistors usually falls within the range of 10 to 30 db; however, some are produced with noise figures between 4 and 6 db. The noise figure for point-contact transistors is approximately 40 db.

As a given transistor's collector voltage is increased, there will be an increase in the noise output. If the signal frequency that is applied to a transistor is increased, the amount of noise produced will decrease.

Symbols

The transistor symbols that are in common use are shown in figure 4-20. The *NPN* transistor symbol (fig. 4-20 (A)) is distinguished by the arrowhead pointing away from the base.

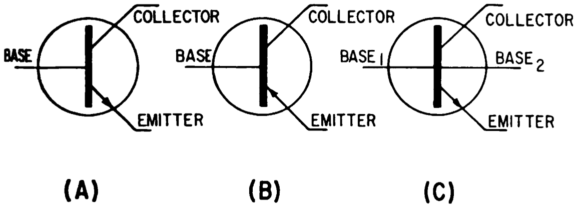


Figure 4-20.—Transistor symbols. (A) NPN; (B) PNP; (C) NPN tetrode.

You can easily recognize the *NPN* symbol by associating it with the phrase "Not Pointing iN" which means the arrow is *not* pointing towards the base. Figure 4-20 (B) shows the symbol for the *PNP* transistor. It is distinguished by the arrow pointing toward the base. This symbol may be easily recognized by associating it with the phrase "Pointing iN Point."

Figure 4-20 (C) shows the symbol for an *NPN* tetrode transistor. If the direction of the arrow is reversed, the resulting symbol will represent the *PNP* type.

Characteristic Curves

As in vacuum tubes, characteristic curves are used in transistor circuit design. The transistor characteristic curves are based on current since transistors are current control devices. The curves are based on collector currents (I_c) and collector voltages (V_c) for different values of emitter currents. (The value that determines collector current is emitter current and not collector voltage.)

Figure 4-21 shows the V_c and I_c charact istic curves for a typical transistor using grounded-base connection. Notice that emitter-bias currents (I_e) are negative value, showing bias polarity on the emitt In the *PNP* transistor curves the emitter-b currents are positive but the collector curre (I_c) and the collector voltages (V_c) are in cated with negative signs.

BASIC TRANSISTOR CIRCUITS

There are three basic circuit configu tions for transistors with which the technic should be familiar. These three circuits be compared to the three basic circuits u in vacuum-tube applications. The names these transistor circuits are the GROUND BASE, same as grounded grid; the GROUND EMITTER, same as grounded cathode; and GROUNDED COLLECTOR, same as the ca ode follower. Figure 4-22 compares the tr sistor circuit with its related vacuum-tube c cuit. Junction transistors may be used in of these circuits. The point-contact transis can only be used in the grounded-base circ because it becomes unstable (oscillates) others.

Grounded-Base Circuit

In the grounded-base circuit the base is common point for applying bias voltages is the reference point for input and out signals. (See fig. 4-22 (A).) The characte istics of the grounded-base amplifier are input impedances, high output impedances, no signal inversion (phase reversal) betw input and output. Also, the circuit gives m erate power and voltage gains.

Grounded-Emitter Circuit

This is the most commonly used transis circuit configuration. It gives about the sa voltage gain as the grounded-base configur tion; however, it gives a much greater po gain. Since the base current controls the c lector current, it also has CURRENT GA

The current gain is possible because base current is the difference between emit and collector current. For example, if a gi transistor has an ALPHA (α) of 0.95 and emitter current of 2 ma., it will have a coll tor current (I_c) of 1.9 ma. and a base curr (I_b) of 100 μamps.

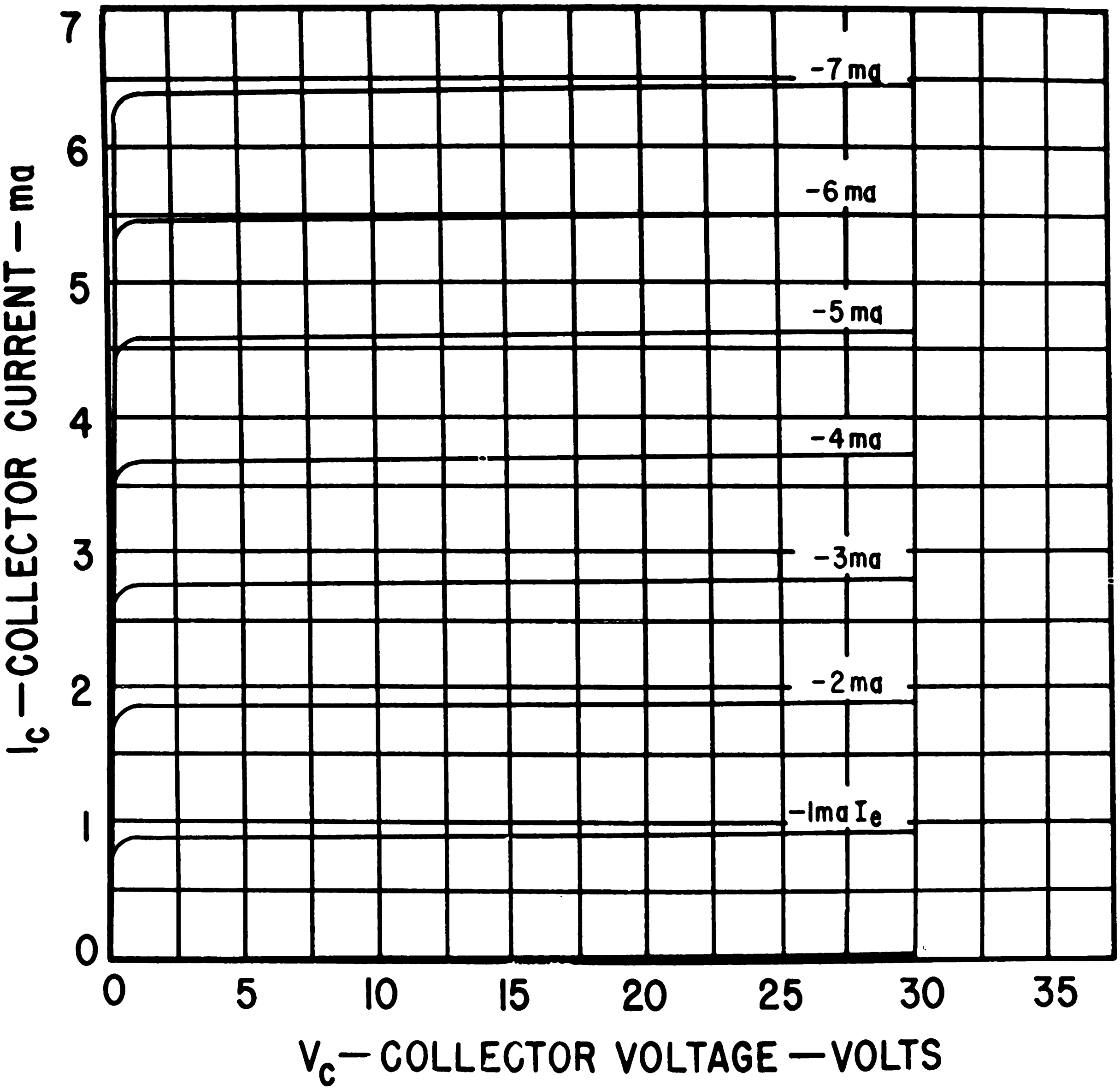


Figure 4-21.—V_c and I_c characteristic curves for an NPN-junction transistor.

Explanation:

$\alpha = 0.95$ and $I_e = 2$ ma.

$I_c = I_e \times \alpha$

$\therefore I_c = 2 \text{ ma.} \times 0.95$

$I_c = 1.9$ ma.

$I_b = I_e - I_c$

$\therefore I_b = 2 \text{ ma.} - 1.9 \text{ ma.}$

$I_b = 0.1$ ma. or 100 μ amps.

Since base current I_b (the controlling current) is 100 μ amps and collector current I_c is 1.9 ma., the current gain is 19. This can be shown by using the following formula for current gain—

$$\text{current gain} = \frac{\text{collector current}}{\text{base current}} = \frac{I_c}{I_b}$$

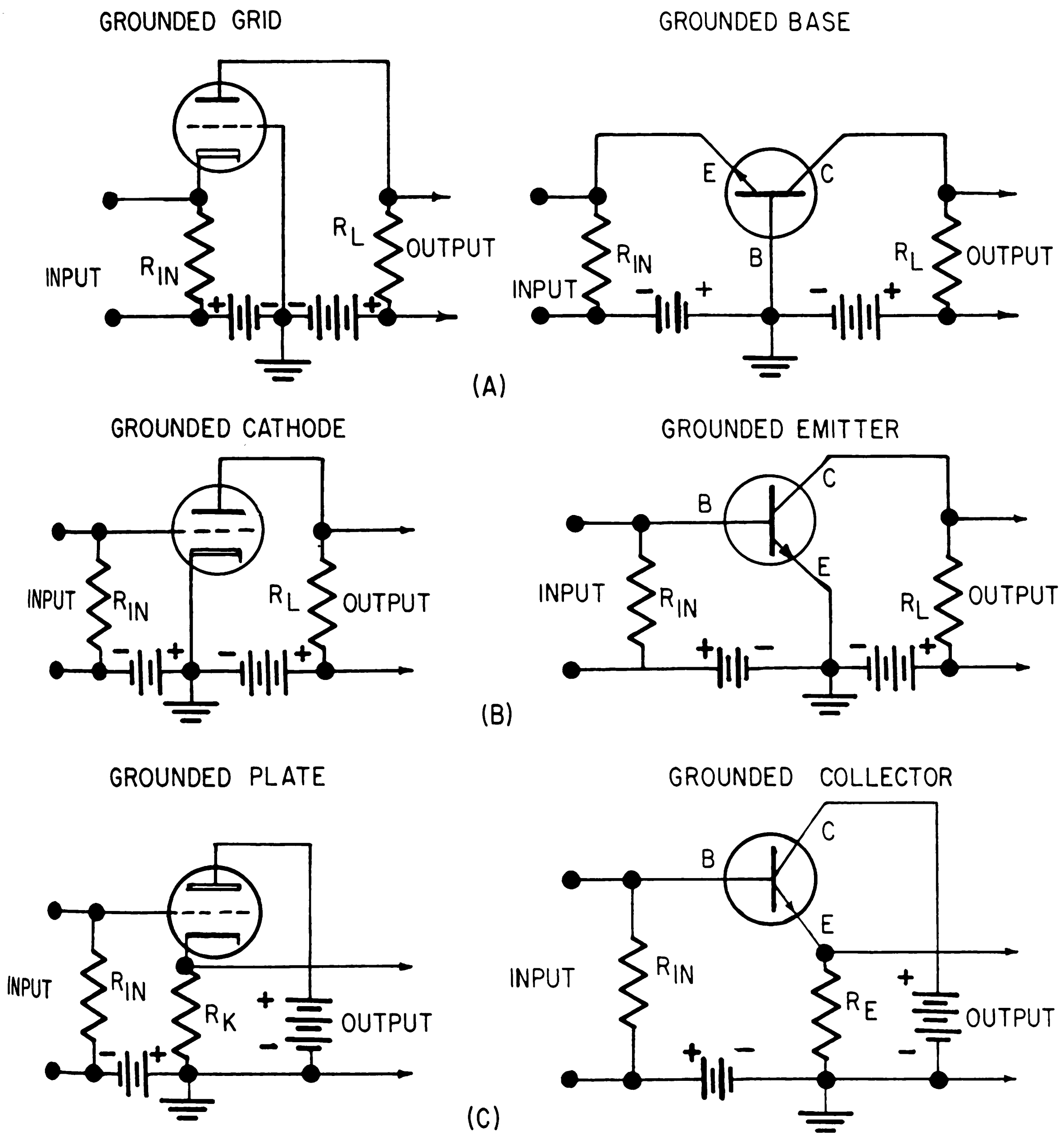


Figure 4-22.—Basic transistor circuits and their comparable vacuum-tube circuits.

$$\therefore \text{ current gain} = \frac{1.9 \text{ ma.}}{100\ \mu\text{amps}}$$

$$\text{current gain} = 19.$$

This current gain may be obtained only from transistors that utilize the common-emitter connection. (NOTE: Some manufacturers give this value in their transistor characteristic charts.) Current gain is assigned the symbol BETA (β).

Another method for calculating current gain is by using a given transistor's alpha figure. For example, if ALPHA equals 0.95 and

$$\beta \ (beta) = \frac{\alpha \ (alpha)}{1 - \alpha \ (alpha)}$$

Then

$$\beta = \frac{0.95}{1 - 0.95}$$

$$\beta = \frac{0.95}{0.05}$$

$$\beta = 19.$$

The input impedance of the grounded-emitter connection is higher than the input impedance of the grounded-base connection. This impedance may be as high as 1,000 ohms. The output impedance of the grounded-emitter connection is lower than the grounded-base connection and is approximately 50,000 ohms.

The signal may be traced through this type circuit by considering the changes in voltage across the input resistor R_{IN}. (See fig. 4-22 (B).) If the applied signal is positive going, it will cause the emitter-base bias to increase, causing an increase in emitter current I_e, and therefore an increase in collector current. An increase in collector current causes an increased voltage drop across R_L and therefore a negative-going signal at the output. If the input signal is negative going, the emitter-base bias decreases, emitter current decreases, collector current decreases, the voltage drop decreases across R_L, and the output signal goes in the positive direction. This grounded-emitter circuit configuration gives signal inversion as in the comparable vacuum-tube circuit.

Grounded-Collector Amplifier

Figure 4-22 (C) shows the grounded-collector circuit and its comparable vacuum-tube cathode-follower circuit (grounded plate). The signal is applied between the base and the emitter and the output is taken from the emitter to ground. Because the input and output of this circuit are common to the emitter circuit (same as cathode follower), the voltage gain is ALWAYS less than one. This is true because the signal output of the emitter degenerates (reduces) the input signal. The degenerative action results in a very high input impedance to this circuit. The input impedance is approximately 500,000 ohms and the output impedance is around 100 ohms. The output signal taken from the emitter is of the same phase as the input signal.

As in the cathode-follower circuit, the grounded-collector circuit has some power gain and is used mainly for impedance matching.

APPLICATIONS

At the time this course is being written, the Navy has made limited use of transistors. The main application of transistors in naval aviation has been in aircraft intercommunication systems (AIC-15). There is, however, an increasing number of different aircraft equipments being build or planned that use transistors.

The four transistorized circuits that follow are presented to show the feasible applications of transistors. In addition to the transistors, the other components in the circuit are typical of those commonly used with transistors. Because of their limited use, no application is shown for point-contact transistors.

Oscillators

The junction transistor may be used in audiofrequency or radiofrequency oscillator circuits. Figure 4-23 shows a typical audio-oscillator circuit.

Transformer *T*1 couples part of the collector output signal to the base and gives a 180° phase shift to this collector signal. This feedback is then in phase with the base signal so that oscillations are sustained. *T*1 must have a low impedance winding for the base-to-emitter circuit and a high impedance winding for the collector circuit.

*Q*1 is a *PNP* junction transistor (*Q* is the standard schematic designation for transistors). Resistor *R*1 sets base-to-emitter bias and its resistance depends on the particular type of transistor used. *R*2 is used to develop some of the audio signal so that it may be coupled out through *C*2. *B*1 supplies bias voltage for both the collector and the emitter circuit. *C*1 is an electrolytic capacitor used t

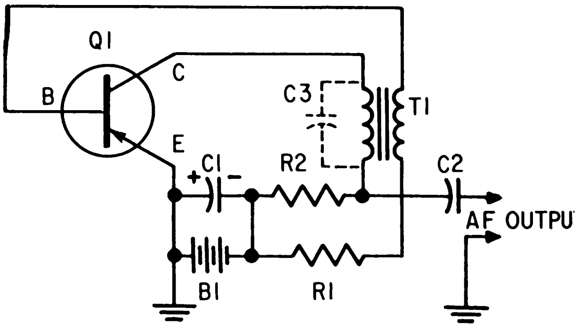


Figure 4-23. –Transistor audiofrequency oscillator usin inductive feedback.

bypass any aduio that may be developed across *B*1.

The inductance and distributed capacity of the windings in *T*1 will determine the output frequency of the oscillator. The frequency may be controlled to an exact value by connecting a specific value of *C*3 across the collector winding. The resultant frequency will be lower than the natural resonant frequency of the transformer alone.

Figure 4-24 shows a typical radiofrequency oscillator. The highest frequency at which this oscillator can operate depends on the upper operating frequency limits of the particular transistor used.

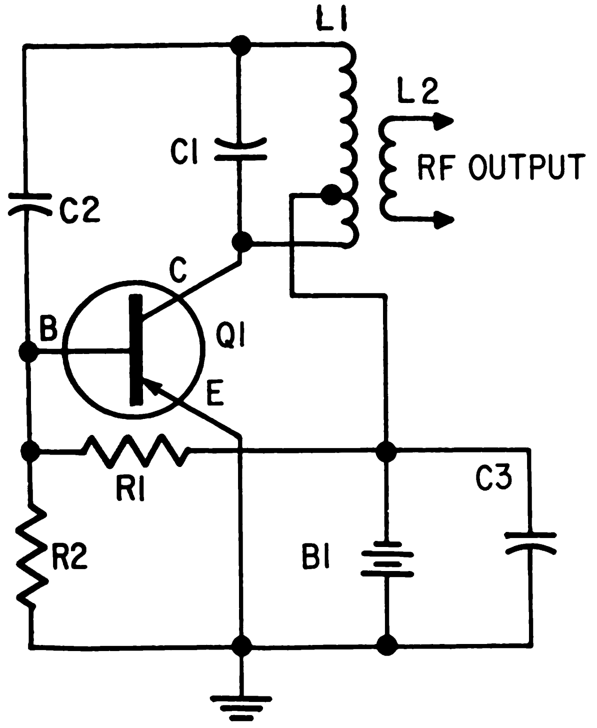


Figure 4-24.—Hartley-type transistor radiofrequency oscillator.

The oscillator utilizes a Hartley-type circuit that contains a transistor (*Q*1) in place of a vacuum tube. *Q*1 is a *PNP* junction transistor. *L*1 and *C*1 form the resonant circuit that determines the frequency output of the oscillator. *L*2 is used to couple the RF signal out. The feedback signal is taken from the top of *L*1 (180° out of phase from the bottom of *L*1 and from the collector) and coupled to the base by C2 to sustain oscillations. *R*1 and *R*2 constitute a voltage divider that provides a proper and stable base-to-emitter bias. *C*3 is a bypass capacitor used to keep the top of battery *B*1 at RF ground for proper oscillator operation.

The circuits presented here are only two of many possible types of transistor oscillator circuits. As with vacuum tubes, there are also many types of crystal oscillator circuits possible.

Amplifiers

Transistors may be used in many types of amplifier circuits. They may be cascaded and use direct coupling, R-C coupling, or transformer coupling. They also may be used in circuits using negative feedback or in power amplifier circuits using single-ended class A operation or in push-pull class A or class B circuits. Transistors are also used in RF amplifier applications (transmitters or receivers) using either class A, B, or C operation.

The transistor circuits used in all of these amplifier applications are very similar to those circuits used with vacuum tubes. However, because of their different impedance, temperature, and voltage considerations, certain important changes must be made to transistor circuits. Two transistor audio-amplifier circuits will be discussed in order to show these outstanding differences.

Figure 4-25 shows an R-C coupled two-stage transistor amplifier with d-c stabilization. This two-stage amplifier is a typical cascaded amplifier using transistors. With the R-C coupling used here the full gain of the transistors cannot be realized. This is because of the low input impedance and high output impedance of the transistor. Q1's high output impedance (collector) is feeding the very low input (base-to-emitter) impedance of *Q*2. With this great mismatch the gain of these two stages is greatly reduced. If other than a very low impedance device is used for the input source of this amplifier, there would be a great loss in the signal at the input.

*Q*1 and *Q*2 are *PNP* junction transistors connected in the grounded or common emitter configuration. *C*1 is the input coupling capacitor, *C* 3 the interstage coupling capacitor, and *C* 5 the output coupling capacitor. The size in capacity and the voltage rating of these coupling capacitors differ greatly with the coupling capacitors used in vacuum-tube circuits. Because of the low impedances present in the circuits, the capacitors must be very large in

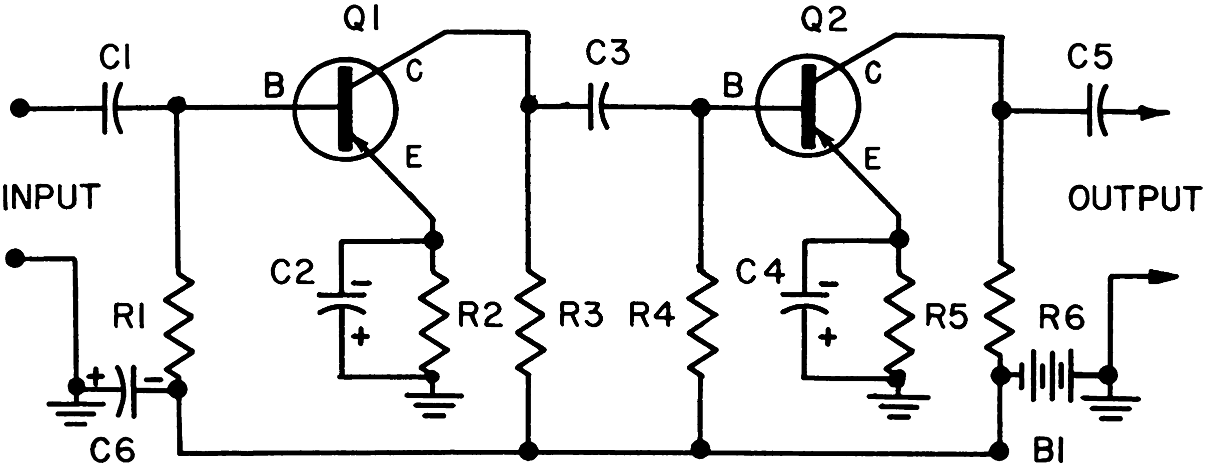


Figure 4-25.—Two-stage transistor amplifier with d-c stabilization.

value. For example, *C*1, *C*3, and *C*5 should be electrolytic capacitors from 5 to 25 μf. in value. In direct opposition to this is the voltage ratings of the capacitors. Where capacitors that are used in vacuum-tube circuits are normally rated from 200 to 500 volts, capacitors used with a transistor may be rated anywhere from 1 to 50 volts. High-capacity low-voltage capacitors are not only used in the coupling of transistors but also for bypassing and decoupling purposes.

Resistors *R*1 and *R*4 are base biasing resistors used to set the correct emitter-to-base bias and to develop the input signals to *Q*1 and *Q*2, respectively. *R*3 and *R*6 are collector load resistors used to develop the output signals of *Q*1 and *Q*2.

The R-C combinations of *C*2*R*2 and *C*4*R*5, connected in *Q*1 and *Q*2's emitter circuits, are for d-c stabilization of these transistors. (NOTE: These R-C networks must not be confused with cathode-bias networks used with vacuum tubes.) Resistors *R*2 and *R*5 are used to compensate for temperature variations and for correcting for differences in transistor characteristics should *Q*1 and *Q*2 be replaced with new units.

As explained earlier in this chapter, transistors are very sensitive to temperature variations. For example, if the temperature of *Q*1 and/or *Q*2 is externally increased, the internal resistances would decrease and their collector currents would increase, causing a further rise in temperature. This temperature rise again lowers the resistance, causing still more current to flow. This action continues at an extremely fast rate until the transistor is destroyed. *R*2 and *R*5 in the emitter circuit prevents this self-destruction of the transistors

For example if *Q*1's temperature rises, the collector and emitter current would try t increase but *R*2 would limit the current increase. At the same time the small voltag increase that results across *R*2 causes a decrease in the emitter-base bias voltage whic in turn holds the collector current relativel constant. The action of this d-c stabilizatio keeps the transistor from destroying itself du to temperature increase, but it will not kee the transistor's gain from decreasing with th increase in temperature.

The electrolytic capacitors *C*2 and *C*4 across *R*2 and *R*5 respectively, are used t keep the emitters at a-c ground so that ther will be no degenerative action on the signa *B*1 is the common bias supply for both th emitter and the collector circuits. *C*6 is large electrolytic bypass capacitor that keep the common bias supply at audio ground.

Figure 4-26 shows a two-stage transisto amplifier using transformer coupling. Th gain of this amplifier would have approximatel one and one-half times the gain of the ampl fier in figure 4-25. The reason is that the co lector impedance of *Q*1 is matched to the lo base-emitter impedance of *Q*2 by the stepdow transformer *T*2.

Input transformer *T*1 matches the sign source to the low base impedance of *Q*1. *T*2 a stepdown interstange transformer and *T* the output transformer, matches the relative high output impedance of *Q*2 to the load.

Two methods of obtaining base-emitter bi are shown. *R*1 and *R*2 constitute a volta

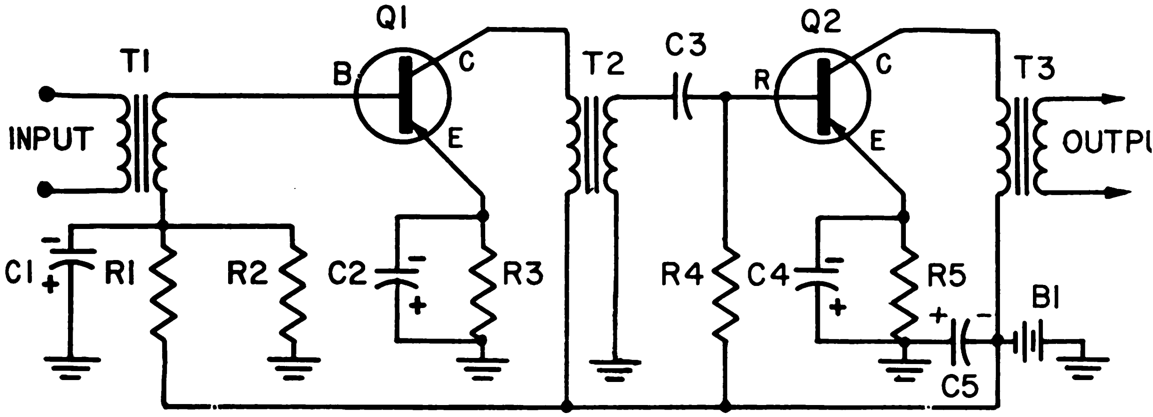


Figure 4-26.—Transistor amplifier using transformer coupling.

divider method of obtaining this bias. This is an excellent method for obtaining a stable base-emitter bias but d-c current must flow through *T*1. If the transformer used is very small and delicate and the wire used in the winding is extremely small, the method of capacity coupling to *Q*2 is preferred. When this method is used, one side of the secondary of *T*2 is grounded and the signal is coupled to *Q*2 by *C*3. *R*4 is the biasing resistor. *R*3 and *R*5 are the d-c stabilization resistors and *C*1, *C*2, *C*4, and *C*5 are electrolytic bypass capacitors.

Switching

In switching applications, transistors must be able to swing from a nonconducting condition to a conducting condition, or vice versa, very rapidly. That is, there must be minimum distortion of the output signal (square wave). In some switching applications the transistor must be able to handle extremely large amounts of current (amperes) for short periods of time.

A low-power switching application of sistors is their use in multivibrators. multivibrator has an output (square voltage that is switched off and on for a s fied duration of time at a specified or trolled rate.

Where high-speed switching opera cannot be done by relays (relays burn up transistors can be utilized. In this applic the transistor may switch small or amounts of power at speeds in the millic times per second.

The transistors that have been discuss connection with the four circuits just plained are *PNP* units. By switching battery polarities and electrolytic polar *NPN* transistors could just as well have used.

Care and maintenance of transistor transistor circuits is discussed in chap "Aircraft Electronics Maintenance."

Magnetic Amplifiers

A magnetic amplifier is a device which utilizes the saturation of a magnetic core for the purpose of securing amplification of electrical signals or control of electrical devices. It is composed of either one or more saturable reactors in combination with other circuit components (resistors, potentiometers, rectifiers, and capacitors).

The principles of magnetic amplification have been known for over fifty years. Due to the lack of suitable core materials the magnetic amplifier found little use except for dling large amounts of power (control of atrical lighting, electrical furnaces, an forth). Recently, due to the developme high permeability core material, utiliz and development of magnetic amplifiers greatly expanded.

Basically, a magnetic amplifier is an core inductor in series or in parallel wi a-c source voltage and load. The load m either an a-c operated device or a d-c ope device with a suitable circuit.

The main advantage of magnetic amplifiers is their reliability. There are no contacts, moving parts, filaments, or other features that account for many of the failures in other types of amplifiers (except those circuits using transistors). Inspection and maintenance is reduced to a minimum. The life of the magnetic amplifier is indefinite and it is especially suited for aircraft installations where its operation will not be impaired by vibration or shock.

The outstanding disadvantages of magnetic amplifiers are their poor frequency response and time of response. Their time of response is long compared to other types of amplifiers.

In order to understand the theory of magnetic amplifiers, it is mandatory that you understand magnetism and magnetic circuits. This information is given in the Navy Training Course, *Basic Electricity*, NavPers 10086.

PRINCIPLES OF OPERATION

Basically, a magnetic amplifier consists of a controlled variable inductance in series with an a-c power supply and a load resistor. The control action involves changes in the magnetic permeability of the inductance coil with resulting changes in inductance, inductive reactance, and impedance of the load circuit. As a result, changes are made in the current flowing in the load and the voltage developed at the output.

As explained in *Basic Electricity*, inductance (often called electrical inertia) is the primary electrical property of any coil. The inductance value of a particular coil is determined by its physical characteristics; and in general, it can be increased in an air-core winding, for example, by inserting a core made of magnetic material. The reason for this effect can be seen by considering the factors that influence inductance as expressed in the following formula:

$$L = \frac{1.256\, N^2 A \mu 10^{-8}}{l}$$

where

L = inductance in henries
N = number of turns
A = area of the core in square centimeters
μ = permeability of the core material
l = length of the core in centimeters.

The permeability of a substance is a measure of the ease with which it conducts magnetic lines of force when compared with some convenient reference material such as air. When air is taken as the standard, its permeabilit in one (1). On this basis, the permeabilit values of ferromagnetic materials, such a iron and steel, range from approximately 6 to 6,000.

From the inductance equation, it can b seen that the inductance of an air-core winding can be increased enormously by insertin a core made of ferromagnetic material. ·Thus if an iron-alloy core with a permeability o 1,000 is inserted, the inductance become 1,000 times greater than the former value wi an air core. The effect of this change whe the coil is used as a series current limitin element can be shown by means of a diagram

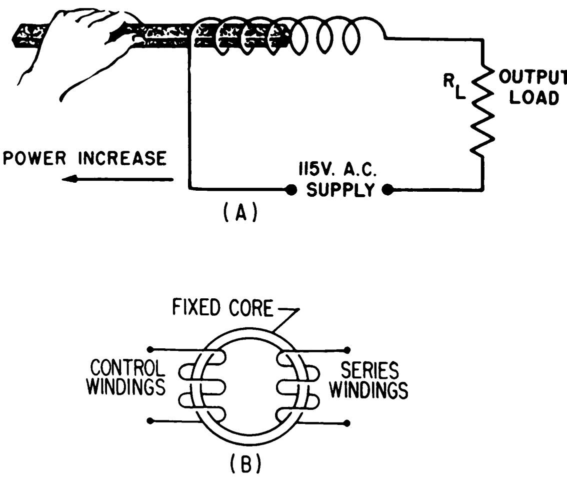


Figure 4-27. –(A) Varying inductance manually; (B) magnetic control.

A very simple circuit is shown in figu 4-27 (A) to illustrate the fundamental contr process. The iron core is moved in and o of the winding to alternately increase and decrease the effective permeability. This vari the inductance and hence the inductive reactance in series with the load resistor. Wh the core is completely within the winding, t inductive reactance is maximum and the voltage drop across the coil is a large fraction the applied voltage. As a result, the load voltage is low and the current flow is minimum.

Removing the core from the coil (fig. 4- (A)) lowers the inductance, decreases t inductive reactance, and permits the curre to rise and the voltage drop across the lo resistor to increase proportionately. I means of this simple arrangement, a comparatively small amount of energy is sufficient control the output of a source with a possib rating of several horsepower; and for this reason, the circuit functions as a magnetic amplifier.

In more practical forms of magnetic control, large a-c sources are controlled by a method which gives much the same result as the circuit shown in figure 4-27 (A). In the circuit of figure 4-27 (B), the series winding has a fixed magnetic core; the core's permeability is varied by saturating or unsaturating the material with a relatively small control current applied to the control windings.

When the control current is increased sufficiently to saturate the core, the inductance is lowered, and the reactance is then about the same as that of an air-core winding under similar conditions. With a reduction in control current, the core becomes unsaturated, the reactance increases, and the output current and voltage decrease. The principal features of this process can be made clear by reviewing some of the basic magnetic concepts and by considering the magnetization curve of a typical core material.

It will be recalled that when current flows in a coil, there is a resulting magnetomotive force, which in the magnetic circuit is comparable to applied voltage in the electric circuit. The strength of the magnetomotive force is determined by the ampere turns, the product of the current flowing in the coil and the number of turns.

The magnetomotive force produces magnetic flux consisting of closed lines of force that are comparable to current in the electric circuit. The quantity of flux, or the total number of lines, varies directly with the amount of magnetomotive force but inversely with the reluctance of the path comprising the magnetic circuit. Magnetic reluctance, the quantity similar to electrical resistance, is a property of the material in which the flux lines are established; and in the case of the electromagnet, or coil, the reluctance value is determined principally by the nature of the core.

The reluctance of an air core remains constant regardless of the applied magnetomotive force and the quantity of flux. However, when a ferromagnetic substance is used as a core material, the reluctance is no longer constant. Instead, as the magnetizing current begins to flow, the reluctance is low and the resulting flux is very high compared with the flux existing in an air-core coil under similar conditions. As the magnetizing current is increased, the reluctance increases and the rate-of-f
increase falls off.

When the current reaches a certain va
depending on the core material, the relucta
increases very rapidly, its value approac
that of air. In this condition, further incre
of the magnetizing current produces a c
paratively small increase in total flux and
core is said to be saturated.

The condition of saturation and the resul
effects on permeability and inductance ca
illustrated by the curve shown in figure
(A). In this graph, the flux density (B)
typical material is plotted against the n
netizing force (H), which is proportiona
applied ampere turns. The ratio of the
values, or B/H, is equal to the permeab
of the material. (See fig. 4-28 (B).) F
the shape of the permeability curve, it is
that permeability is not constant but has
ferent values for different amounts of magne
ing force.

From point *a* to *b* (fig. 4-28 (A)), the c
rises steeply in what is substantially a stra
line. In this region, the permeability is
and the coil has a large inductance va
From point *b* to point *d*, a small change
produces a much smaller change in flux de
than on the linear part of the curve. Here,
permeability is lower and the inductanc
correspondingly smaller. From point *d* to p
e and beyond, the curve is almost flat, indi
ing a very small increase in B as H is
creased. In the latter condition, the cor
saturated and the inductance is minimum.

Since the basic control action of the n
netic amplifier depends upon changes in ind
ance, the region between points *b* and *d*
4-28) represents the ideal operating ra
If the action is such that control signals s
the magnetization about point *c*, comparati
small changes in input result in large va
tions in output-circuit impedance. In r
modern applications of magnetic amplifi
the saturation method is used since it sin
fies the operation, permits faster respo
and eliminates moving parts.

Saturable Reactor Cores

For optimum performance, the laminat
of a saturable reactor core should be arra
so that the air gap is as small as possible,
the laminations should be very thin so a
reduce eddy current effects to a minimum
lamination is a single piece of the metal f

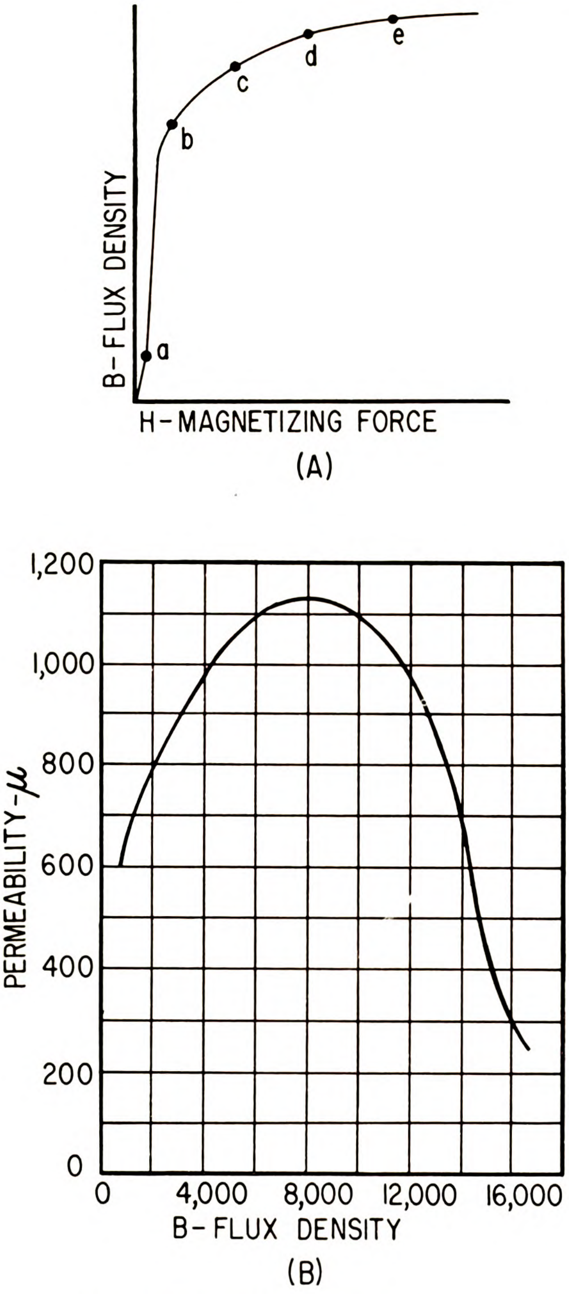


Figure 4-28. –(A) Magnetization curve; (B) permeability curve.

which the core is made. The usual interleaving technique used in conventional transformer core construction is unsatisfactory for saturable reactors in magnetic amplifiers. The many small air gaps provided by butt joints of the standard *E* core distort the magnetization curve, thus making it inadequate for the peak performance necessary in most applications. Special design of the *E* core ha improved its characteristics by increasing th overlap of the laminations for a greater portic of the magnetic path; however, its performanc is somewhat below that desired.

Saturable reactor core material should hav low hysteresis and eddy current losses, hig saturation flux density, stable magnetic characteristics, and a hysteresis loop that i rectangular.

The most common core construction use in the better saturable reactors is made b spirally winding a relatively narrow silic steel tape into a circular (toroidal) or rectangular core as required. A toroidal saturab reactor is shown in figure 4-29. The tap cores are mounted in containers to provic support for the multilayer windings; also, th assures that no mechanical strain will be place on the core. Another type saturable reacto core is made by stacking single-piece stampe laminations.

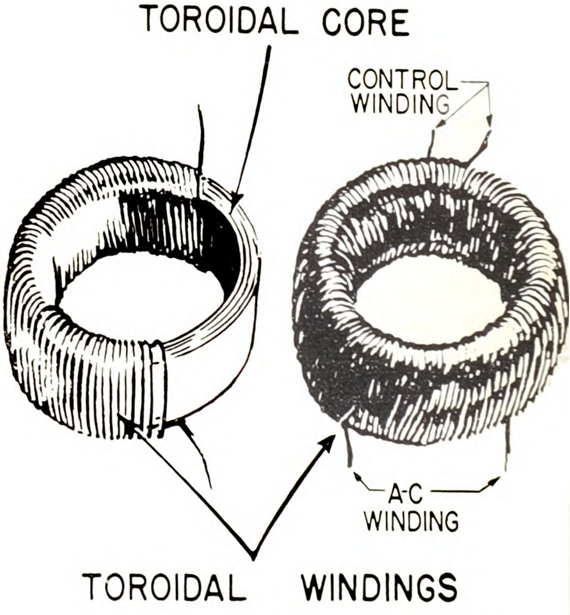


Figure 4-29.–Toroidal saturable reactor.

Since tape wound cores have no center le two cores are required in most amplifier The control windings are connected in series aiding so that a common control current ca saturate both cores. The a-c load winding are connected in series-opposing to minimi the alternating current induced in the contr circuit.

The physical arrangement of the variou toroidal windings (fig. 4-29) on the cores wi greatly affect the performance of the magnetic amplifier. They must be wound in such a way that leakage effects are reduced to a minimum and the circulation of alternating current in the d-c control, bias, and feedback windings are minimized. The operation of bias and feedback windings will be discussed later in this chapter.

Typical magnetic amplifiers utilizing toroidal wound saturable reactors will be discussed under the heading "Magnetic Amplifier Applications." The use of bias, feedback, and cross-over windings on these reactors will also be discussed later in the chapter.

Rectifiers

The most common types of rectifiers used in magnetic amplifiers are copper-oxide, selenium, germanium, and silicon.

These rectifiers must have certain characteristics if optimum operation is to be obtained from the magnetic amplifiers. They must possess characteristics of low reverse current, low forward resistance, high forward-to-reverse current ratio, high peak inverse voltage rating, and must not be affected by extreme ambient (surrounding) temperature changes.

BASIC CIRCUITS

The various forms of magnetic amplifiers used in practical applications have certain circuit elements in common, including d-c or a-c control windings; dry-disk rectifiers; special forms of magnetic cores; biasing coils; and feedback circuits. Among the processes of importance are hysteresis effects and the actions determining speed of response of the amplifier.

In this section, these components and processes are introduced by considering first a basic circuit to illustrate the fundamental method of control. This circuit is then developed into more complex form by addition of components which improve the circuit operation.

The basic arrangement of components for controlling a-c load power by means of a control coil is illustrated in figure 4-30. Two windings are required, both of which are wrapped on a common core. The CONTROL WINDING, shown on the left, is supplied from a d-c source, and the control current is adjusted by a potentiometer. It is the purpose of the control current to establish a unidirectional flux in the core with an intensity determined by the d-c ampere turns of the control circuit. The second coil, the LOAD WINDING, is connected in series with an a-c power source and the load resistance, which in this case is a lamp.

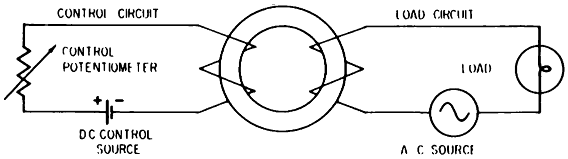


Figure 4-30.—A simple magnetic amplifier.

With the circuit (fig. 4-30) operating on the knee of the magnetization curve, a small increase in control current lowers the inductance of the load winding. This occurs because the degree of magnetization is shifted to a point on the curve where the slope approaches the horizontal, and the permeability of the core material is thereby decreased. (See fig. 4-28 (B).) As a result, the inductive reactance of the load winding is lowered; the total load-circuit impedance falls off; and the load current rises, causing the power developed in the load to increase.

If control current increases enough to saturate the core completely, the load winding reactance drops nearly to zero, leaving the resistances of the winding and of the load as the principal current limiting elements. In this condition, maximum supply voltage is applied to the load, and the lamp then glows at maximum brightness.

On the other hand, decreasing the control current causes an increase in the reactance of the load winding since the operating point is moved toward the steep part of the curve, thereby increasing the permeability. With the coil at maximum inductance, there is a corresponding minimum value of load current and consequently minimum load power. Thus, for a small change in control power, the magnetic action produces a large change in load power, so that the device functions as an amplifier.

Although the explanation just given illustrates the basic method of controlling core permeability, the arrangement shown in figure 4-30 is seldom used because it is a very inefficient magnetic amplifier. Transformer action takes place so that energy is coupled from one winding to another. The alternating flux resulting from secondary, or load current, induces voltage into the control winding. If the control coil has a large number of turns, the induced voltage may become excessive and may even break down the insulation. Even if the coupled voltage is small, the control circuit acts as a low-resistance winding and dissipates a considerable amount of energy that would normally be applied to the output.

The induced a-c voltage in the control winding alternately adds to and subtracts from the control voltage.

It is possible to reduce the losses resulting from unwanted coupling by inserting an isolating impedance in the form of an inductance placed in series with the control winding; or losses may be minimized by the use of a three-legged core. The latter method is described in the following pages.

Three-Legged Magnetic Cores

A more satisfactory circuit arrangement results when the basic amplifier is modified as shown in figure 4-31. This device is often employed for controlling large amounts of alternating current. It contains a three-legged core with an a-c winding on each outer leg and a d-c control winding on the center leg. The chief advantage of this core structure is that alternating flux components produced by currents in the load windings are balanced out in the center leg and do not affect the control circuit. However, this desirable condition exists only if the two a-c coils have equal numbers of turns and are wound so that the flux lines oppose, as indicated by the dotted line in the drawing.

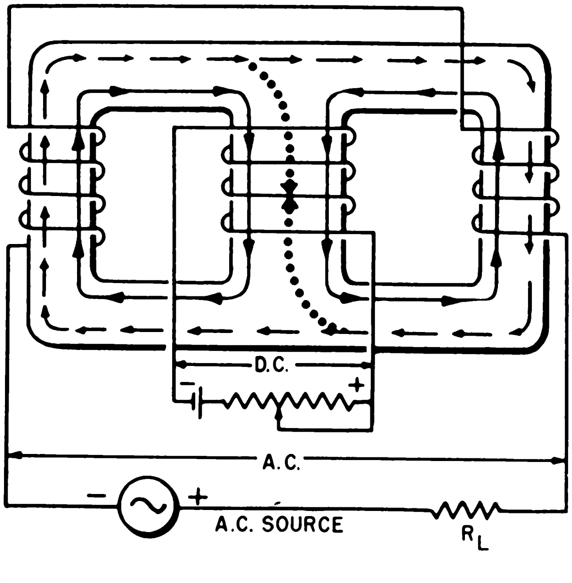


Figure 4-31.—Magnetic amplifier with three-legged core.

While alternating flux does not pass effectively through the center leg (fig. 4-31), th two components add along the path through th outer legs of the core as indicated by th broken lines. The drawing also shows tha the control current produces a magnetic flu (represented by solid lines) that magnetize the entire core of each load winding. Thus while the d-c coil can influence the operatio of the load circuit, there is no coupling o energy by transformer action from the loa circuit to the control winding.

During normal operation, variations of th control current result in corresponding change in core permeability; and this, in turn, readjusts the inductive reactance in series with th load. As far as the control process is concerned, the operation of this circuit is simila to that of the basic magnetic amplifier o figure 4-30, hence it is classed as a nonfeedback amplifier.

Figure 4-32 (A) shows the preferred metho of constructing a saturable reactor that possesses the same characteristics as the three legged core type. This arrangement prevent interaction and also conserves space. It use two separate circular cores (toroids) that ar stacked coaxially. Each core contains an individual a-c winding. The cores are the stacked so that the a-c windings are wound i opposite directions. A common control windin is wound around both cores after stacking. Thi arrangement prevents a.c. from being couple into the control winding.

Figure 4-32 (B) is the schematic of a magnetic amplifier using stacked cores.

Magnetic Amplifiers With Half-Wave Rectifiers

The operation of the simple amplifier (fig 4-30) is inefficient; and it has an additiona disadvantage in that relatively large amount of control current are required. This is because the control ampere turns must overcome the effects of the comparatively larg a-c load current, which establishes sinusoidall varying magnetic flux in the core. The intensit and direction of the magnetic field produce by load current when no control current i flowing can be shown better by a hysteresi curve, as in figure 4-33,

The interpretation of the hysteresis curv for typical core materials is given in detail i *Basic Electricity*, NavPers 10086. It is sufficient here to note that the magnetizing forc

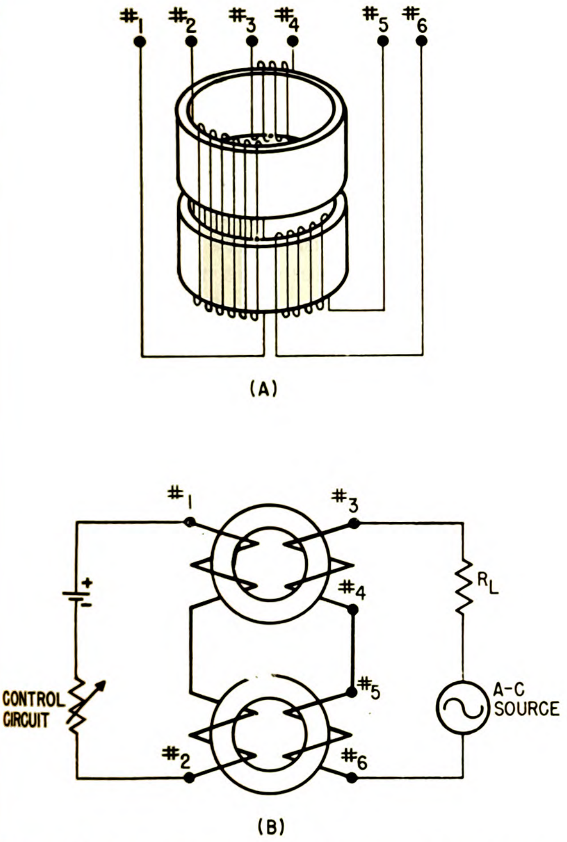


Figure 4-32.—(A) Stacked-core saturable reactor; (B) schematic of a magnetic amplifier using stacked cores.

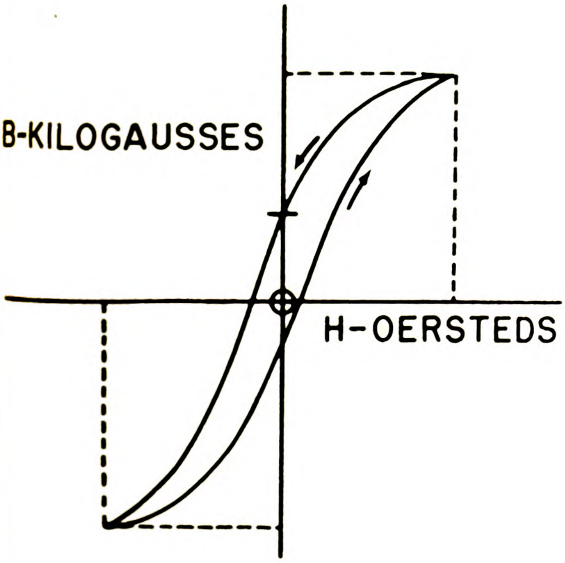


Figure 4-33. —Hysteresis curve.

(expressed in oersteds) varies along the h
zontal axis of the graph in accordance with
a-c current applied by the power sources.
a result, the magnetic flux density (in gaus
has values both above and below the zero l
(fig. 4-33), indicating a regular change in di
tion of the flux lines. Thus, in the opera
of the magnetic amplifier, the flux create
the load current impedes the control flux
ing one half cycle and aids it during the ot

In order to produce sufficient flux to
ance out the oscillating flux of the load c
rents, the ampere turns provided by the c
trol winding must equal the ampere turns of
load windings. In addition, sufficient e
control magnetizing force is needed to set
operating point at the desired place on
magnetization curve. The combination of t
two demands results in a very ineffec
amplifier since the control-circuit amp
turns must exceed the ampere turns of the
circuit. This difficulty is overcome by u
rectifier units. These units eliminate the
wanted currents and permit self-satura
operation of the amplifier. This amplifie
also classed as an internal feedback type.

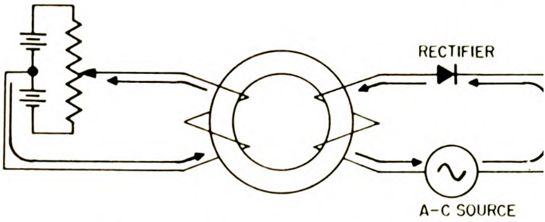


Figure 4-34.—Magnetic amplifier with half-wave rectifier.

A more efficient magnetic amplifier is sh
in figure 4-34. A half-wave rectifier (usu
of the dry-disk type), inserted in the load
cuit, permits current to flow in one direc
only. Because of the unidirectional load c
rent, one-half of the formerly oscillating
is eliminated; and the remaining field
either assist or oppose the control flux,
pending on the position of the arm of the c
trol potentiometer. The arrows in the drav
indicate the direction of electron flow. In
case illustrated, it can be seen by applying
left-hand rule for determining the directio
the magnetic fields, that the load flux ass
the control flux in saturating the core.
moving the arm of the control potentiom
toward the negative end, the fields would
be made to oppose. In either case, howeve

more effective amplifier is provided since less control power is required for a given amount of output power.

The action of the circuit with the rectifier limiting the load current to unidirectional flow can be interpreted as a form of feedback. Since the entire feedback effect takes place within the magnetic circuit comprised of the core and is accomplished without the use of additional coils or control elements, it is classified as internal feedback. The use of additional circuit elements to provide external feedback is discussed in detail in a subsequent part of the chapter. Consider first, the process by which the load circuit is made to assist the control action in the self-saturating magnetic amplifier.

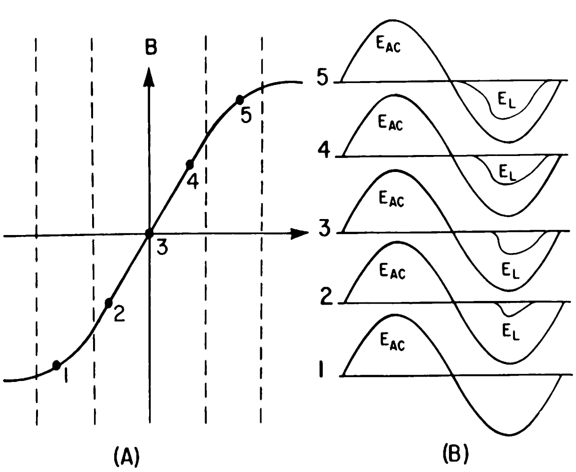


Figure 4-35. —Operation of self-saturating (internal feedback) magnetic amplifier.

Self-Saturating Magnetic Amplifier

The operation of the self-saturating amplifier can be understood by use of a magnetization curve in which the hysteresis effect is eliminated as in figure 4-35. Point 1 on the curve indicates the condition of the control flux when the potentiometer (fig. 4-34) is set to apply a negative control voltage. Under this condition, the control flux is in opposition to the flux resulting from load current. If the amplitude of the load current is such that the total core flux varies along the curve from point 1 to point 4, the impedance of the secondary remains large; and the voltage drop across the load resistor is very low. The relation of the applied voltage to the load voltage is shown in the lower drawing of figure 4-35 (B).

When the potentiometer arm is moved towar the positive end, the control current flows i the same direction as before but with less amplitude. The rectified load current then varie the core flux between points 2 and 5 on th magnetization curve (fig. 4-35). Under thi condition, partial saturation of the core results, and the output waveform resulting i shown in drawing 2 of figure 4-35 (B).

As the potentiometer is moved nearer th positive end, placing the operating point t position 3, the control current is then zer The resulting waveform at the output is th shown in drawing 3 of figure 4-35 (B). A position 4, the control voltage and current ar reversed with respect to the original directio producing a corresponding reversal of contr flux. In this condition, the control flux assist the load flux and saturation is reached at a earlier instant in the a-c cycle. The resultin output is shown in drawing 4; while drawing of the same figure shows the output curren when the control voltage is made even mor positive.

Effects of Hysteresis on Operation

In the preceding discussion of the basic magnetic amplifier, the magnetic characteristic of the core material are largely neglected, an emphasis is placed on the function of the fundamental components. In order to understan fully the operation of self-saturating amplifier it is necessary to consider the shape of th hysteresis loop and its significance in circu operation.

The B-H curve of a typical magnetic material is shown in (A) of figure 4-36. Assum that this material is used as the core of a magnetic amplifier of the type illustrated in figur 4-34. The amplifier has two distinct period of operation: the interval during which th rectifier conducts is called the operatin period; while the nonconducting half cycle applied voltage is called the control perio The solid line of the hysteresis loop in (A) indicates the variation of flux within the cor when the control voltage is set at zero so th no control current flows. During the operatin period, the load current, which is assumed t be of sufficient amplitude to saturate the cor swings the flux from point *o* on the curve t point *a*, the saturation value.

At the end of the first operating period, th degree of magnetization returns, not to th original starting point, but to point *b* (fig. 4-3

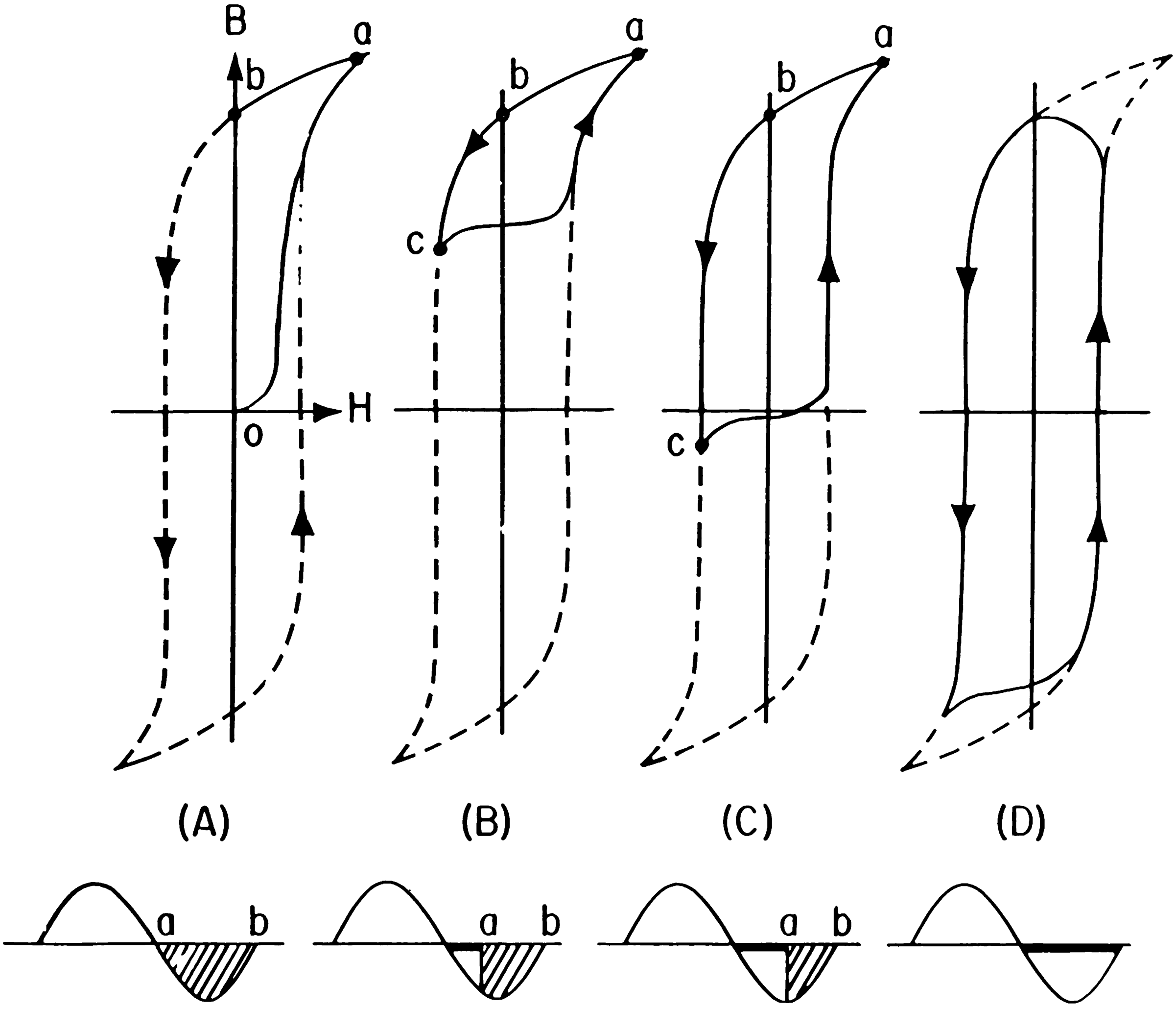


Figure 4-36.—Operation of magnetic amplifier showing effects of hysteresis.

because of retentivity of the core. (This value on the graph is called the remanence point. It indicates the amount of flux left in the material when the magnetizing force is removed and is also a measure of the usefulness of the material to serve as a permanent magnet.) The part of the hysteresis loop shown in broken lines in (A) of figure 4-36 represents the further change in magnetization that would occur if the magnetizing current were permitted to reverse in direction to complete the normal hysteresis graph.

The core remains magnetized at the remanence point during the control period of the amplifier. During each following half-cycle operating period, the material saturates immediately; and the load current is maximum since no control is exercised. The output waveform for this condition of the control circuit is shown directly under the loop drawing (A) of figure 4-36.

Figure 4-36 (B) shows the operation when a small control current is flowing in a direction to cause the control flux to oppose the load-current flux. The initial change in core magnetization is similar to that just described; but when the load current becomes zero, the total flux is placed at the value indicated by point *c* during the second control period. This process of positioning the residual magnetic flux is called resetting.

Following the resetting action, the next operating period causes the flux to increase; and a small part of the applied half cycle elapses before saturation is reached with the core at point *a*. At this point, the rectifier is in maximum conduction and remains so for the rest of the half cycle. When the control period is resumed, the flux returns to point *c*, being reset to this value by the action of the control circuit. Thus, the primary function of the control current is to determine the starting value of magnetic flux. The output waveform for this amount of control current is shown directly below (B) of figure 4-36.

Part (C) of figure 4-36 shows the result of increasing the amount of control current. Note that conduction in the output circuit occurs only during the latter half of the operating half cycle. The result of a large amount of control current is indicated in (D) of the figure. In this case, the reset point is such that the load flux cannot drive the core to complete saturation; and therefore, the output current is substantially zero, as shown in the corresponding waveform. The method of operation just described is very similar to the action of a thyratron, in which conduction is either maximum or zero, depending on the relationship of the control voltage and the applied plate voltage. The term firing, which is often used in referring to thyratron action, is also frequently used interchangeably with the word saturation when describing the similar condition in magnetic amplifiers.

Using Bias for Flux Reset

If the core material has hysteresis characteristics that result in a rectangular-shaped B-H curve, it may be necessary to bias the core to retain control. This is accomplished either by causing a bias current to flow through the control winding or by use of a separate bias coil. With either method, the bias current provides the means for resetting the magnetic flux to the initial operating point during the control period of the amplifier as described in the preceding paragraphs. The use of a separate bias winding (separate from control winding) minimizes the loading of the control-voltage source.

The physical position of the bias winding with respect to the control and load coils in a stacked-core reactor is illustrated in figure 4-37. The core may be biased so that with zero control current, the flux resulting from load current saturates the core material midway in the operating period. In this condition, the bias setting corresponds approximately to operating point *c* in figure 4-36 (C), so th the control current can either advance or de lay the point of saturation. Thus, if the polar ity of the control voltage is such that t control-current flux adds to the bias flu saturation is delayed and the amplifier fir later in the operating period. A control sign with opposite polarity results in a contr flux that opposes the bias flux and hence a vances the firing point.

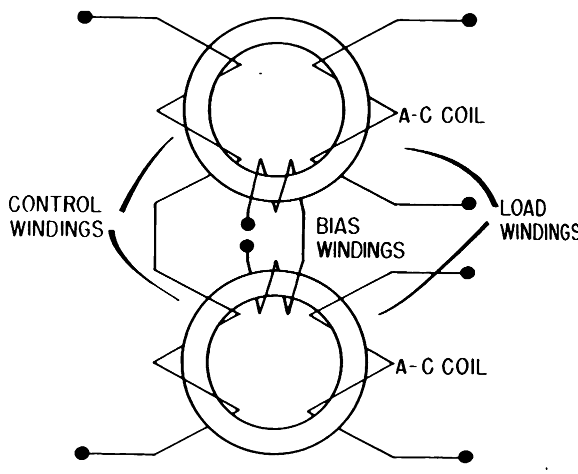


Figure 4-37. —Bias windings on a stacked-core reactor.

In most cases, the polarity of the d-c bi supply is selected so that the bias magnetis opposes the load-current flux. The magnitu of the bias is usually such that the core fl is reset to a point on the hysteresis curve b tween points *b* and *c* in figure 4-36 (B). some applications, the bias polarity is r versed so that it aids the load winding flux a provides quick initial saturation of the co thereby increasing the amplification of we input signals. Also, some types of spec circuits contain a-c bias system; howev these have very limited application in equ ment, that you will be required to maintain detailed description of them is not justifie the present discussion.

MAGNETIC AMPLIFIERS WITH FULL-WAVE RECTIFICATION

In most applications of magnetic amplifie full-wave output is desirable rather than pulsating, or half-wave, operation previo discussed and illustrated. Full-wave opera in which the load is energized during both hal of the a-c cycle may be obtained by usin pair of half-wave units.

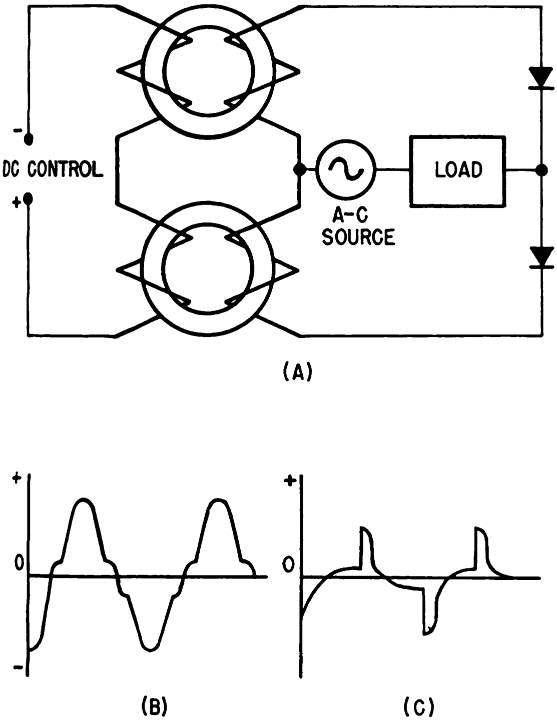


Figure 4-38.—Full-wave magnetic amplifier and output waveforms.

A typical full-wave circuit arrangement is illustrated in (A) of figure 4-38. The load current in the amplifier shown in (A) is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately; and as one unit conducts, the core of the other is reset by the action of the control current. With each rectifier conducting approximately one half cycle, the output current variations are full wave in nature.

Output current waveforms are shown in (B) and (C) of figure 4-38; these waveforms indicate the resultants for two different values of control current. Waveform (B) occurs when the control current sets the core near the point of saturation so that heavy conduction begins early in each half cycle of applied voltage. If control current is reduced to a lower value, the output resembles the waveform in (C), in which the average value of current over each half cycle is considerably less than when the operating point is near saturation. As in the operation of the basic circuit, the output power is varied by controlling the flow of load current; but unlike the half-wave amplifier, current is delivered to the load resistance during both half cycles of applied source voltage.

The magnetic amplifier shown in (A figure 4-38 contains a single control wind and two magnetic cores. These are c bined to form a reactor which operates same as a three-legged core reactor. extremely small air gap separates the magnetic paths; and the combination may regarded as two units similar to the cir illustrated in figure 4-34. The air gap ass in isolating the magnetic flux components sulting from the load coils so that one c remains unsaturated while the other is saturation. The two load coils conduct alt nately but in opposite directions through load resistor; hence the output current wa forms resemble those shown in (B) and

External Feedback in Magnetic Amplifie

It is possible to improve many of the op ating characteristics of a magnetic ampli by the use of an external feedback circuit. many cases, this circuit consists of an ad tional coil wound on the center leg of the m netic core. Feedback action occurs when coil is energized by a portion of the ou current and produces a magnetic field tha combined with the control flux established the input circuit.

Typical feedback circuits are illustr in figure 4-39. Each amplifier contains d disk rectifiers connected in a bridge circ In amplifier (A) the rectifier produces a f wave d-c output both to the load resistor to the feedback winding. Amplifier (B) has load in the a-c circuit and the bridge recti provides direct current in the feedback wi ing only.

Feedback in these amplifiers (fig. 4- may be either positive or negative, depen on the connection of the feedback winding the flux produced by the latter winding the control winding flux, the feedback is po tive, or regenerative; if it opposes the con flux, it is negative, or degenerative.

The effect of positive feedback is to m the circuit more sensitive to changes in c trol current so that extremely high value gain can be achieved. It has the undesir effect, however, of increasing the respo time of the amplifier, and it may also ca instability. The general effect of nega feedback, on the other hand, is to reduce sensitivity with a corresponding increas linearity of the magnetization curve and duction of the time lag.

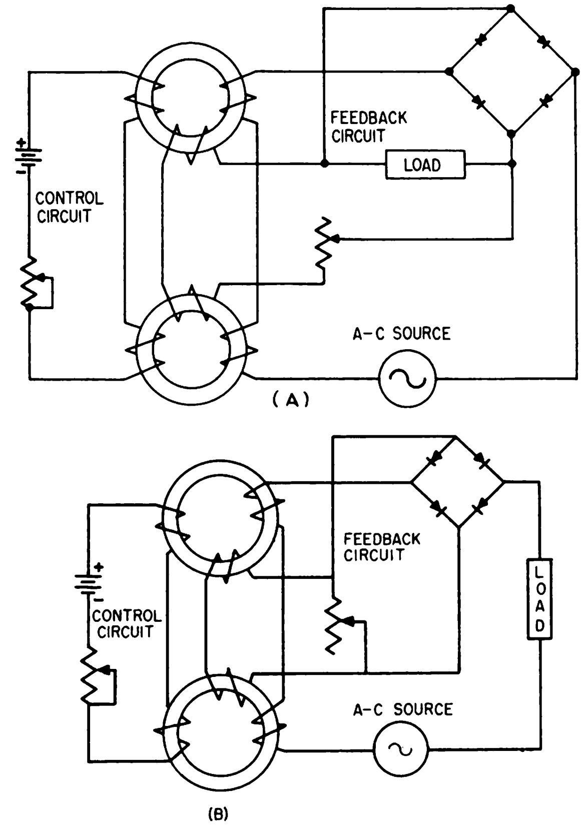


Figure 4-39.—Magnetic amplifiers employing external feedback.

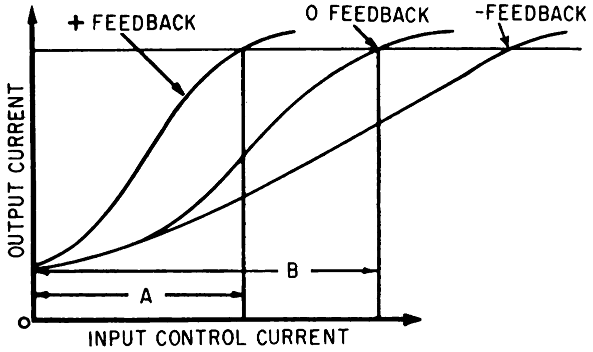


Figure 4-40.—Effects of external feedback.

Load current is plotted against control current in the curves in figure 4-40 to show the effects of feedback on linearity and on the quantity of control current required. The total control current (input plus feedback currents) needed to saturate the core is the same regardless of the sign or the amplitude of the feedback present.

With positive feedback, less control-circuit current is required because of the additive effect of the feedback and control coils. As indicated in figure 4-40, there is a difference between no-feedback saturation current (B) and the control current present with positive feedback (A). This difference is supplied by the output circuit through the feedback winding. When negative feedback is employed, the current drawn by the control circuit must be increased above the no-feedback value to achieve saturation since the feedback flux is in opposition to the control flux. The effect of negative feedback on linearity of control is indicated by the right-hand curve, which is straight over a much larger range of contro current values than the curves for the positive- and no-feedback conditions.

APPLICATIONS OF MAGNETIC AMPLIFIERS

Magnetic amplifiers are used in many kind of equipment, both in circuits which contai electron tubes and/or transistors and in thos which do not. Among these applications ar audiofrequency amplifiers, motor controllers power-supply regulators, and various types c servo systems.

Magnetic amplifiers are used extensively i servo systems. They may be constructed fc use in either low- or high-power circuits. Ai craft equipment that utilizes servos which cor tain magnetic amplifiers are guided missil control, automatic pilots, radar fire contro radar antenna control, and instrumentatio

Another use for magnetic amplifiers is connection with voltage and frequency regu lation. Many aviation electronic equipmen contain voltage regulated power supplies. Th accuracy of the voltage produced by these sup plies is important in so far as proper operati and maximum life of the equipment is co cerned. Magnetic amplifiers are used for co trolling the voltage and frequency of the ai craft's electric power generating systems.

Actual circuit application of magnetic am plifiers is beyond the scope of this course; ho ever, this information is presented in the Na Training Course, *AT 1 & C*, NavPers 1031

ADVANTAGES AND DISADVANTAGES

Advantages

In the operation of military electronic equi ment, there is a serious problem connect with repair and maintenance. And the features which magnetic amplifiers have to offer in the solution of this problem are ease of maintenance, ruggedness, and long life.

The maintenance required by a magnetic unit without rectifiers is about equal to that required by an ordinary transformer. The units which contain rectifiers require more attention, the maintenance requirements and life expectancy being largely determined by the rectifier components. In these, dry-disk rectifiers are generally employed; and these rectifiers are rated at 60,000 hours of normal life for ordinary operational demands.

In its ability to withstand shock and overload, the magnetic amplifier is about equivalent to a transformer of similar size. The factor which is most important in giving it an advantage over the vacuum tube in reliability and ruggedness is its independence of thermionic emission. Hence, its operation does not involve fragile filaments. As an example of its trouble-free performance, it was found by examination of the logbook of the German cruiser *Prinz Eugen*, that not one of the various types of magnetic amplifiers used on that vessel for gun stabilizers and in servos required any sort of servicing for a period of 10 years.

Additional features which make magnetic circuits useful in airborne applications are adaptability, safety, high efficiency with high gain, and readiness for instant operation. The amplifiers can be built in special shapes, thereby allowing installation in confined spaces. They can be hermetically sealed for protection against the environment and easily recessed or built into the associated equipment. Since no heater power and no high-voltage d-c power supplies are required, the total equipment has less weight and occupies less space than comparable electronic installations.

In airborne usage, the magnetic circuit has an advantage from the standpoint of safety. The hermetically sealed assemblies can be operated near combustible material with much less danger from sparking or arc-over than with relays and electronic circuits. Also the elimination of high-voltage power supplies removes one major source of hazard for operating and maintenance personnel.

The overall efficiency of the magnetic amplifier is generally higher than that of equivalent electron-tube amplifiers since some of the losses that occur in tubes are avoided. These include the power for cathode heating, the losses by plate dissipation, and those resulting
from the use of high-potential B-plus suppli
Magnetic amplification is capable of provid
large amounts of gain, both voltage and pow
And as in conventional circuits, the magne
stages can be cascaded to produce any r
sonable amount of voltage or power ampli
cation.

Magnetic amplifiers need no warmup ti
and hence are in a state of continuous rea
ness. This consideration is very importan
equipment such as fire control systems in wh
the amplifiers and other circuits must be re
for instant use.

Disadvantages

The principal disadvantage in the operat
of magnetic amplifiers results from a time
lay which occurs because of the inductive c
cuits involved. The delay, or lag, is the ti
interval between the occurrence of a cha
in control-circuit voltage and the correspo
ing response made by the load circuit.
amount of time lag present varies with
amount of gain provided by the circuit. It
range in value from an interval equal to one
two cycles of the operating frequency to
equal to several hundred cycles. And si
the extent of the delay increases proportional
with the degree of amplification, lag effe
are among the limiting factors in the des
of high-gain magnetic circuits.

A second important disadvantage res
because of the distortion normally present
the output waveforms. These are seldom p
sine waves; and not only is the distortion
jectionable in itself, but it is also accompan
by the generation of many harmonic frequ
cies. The harmonics are very undesirable si
some are of such frequency and amplitude t
considerable interference with nearby equ
ment can take place.

For satisfactory operation, the magne
units must be kept within a range of tempe
tures extending from about -50° to about 1
C. Outside of this range the magnetic prop
ties of the core materials are altered; and al
extremes of temperature have adverse effe
on the action of the dry-disk rectifiers wh
are usually in the amplifier.

Magnetic amplifiers intended for use
power applications at frequencies in the or
of 60 cycles per second are necessarily la
in size in order to provide the required ind
tance. This fact tends to restrict the appli
tion in airborne power systems to operatio
frequencies such as 400 c.p.s. Also, the in

impedance of the typical magnetic circuit is often of incorrect value for matching many types of driving stages, thereby making it necessary to employ impedance-matching networks.

In order to counteract many of these undesirable features, magnetic amplifiers are frequently used in combination with electron-tube or transistor circuits. In these combinations, the conventional amplifiers usually provide most of the voltage gain and comprise the earlier stages of the system. The magnetic circuit is employed as the output, or power, stage and delivers the high-level output signals without the use of high-potential d-c sources.

QUIZ

1. When reverse bias is supplied a PN junction,
   a. current flows
   b. holes and electrons move across the junction
   c. minority carriers in the P-type material combine at the junction with minority carriers from the N-type material
   d. the PN junction potential is decreased

2. Germanium that contains a small amount of arsenic
   a. produces a P-type material
   b. produces an N-type material
   c. contains many free holes
   d. contains few free electrons

3. Which of the following is considered to be the greatest advantage of a transistor over a vacuum tube?
   a. No filament power is required
   b. Small in size
   c. Electrically rugged
   d. Physically rugged

4. Transistors are biased
   a. forward base-emitter and forward base-collector
   b. forward base-emitter and reverse base-collector
   c. reverse base-emitter and reverse base-collector
   d. reverse base-emitter and forward base-collector

5. The alpha of a transistor is given as 0.96. What is the beta?
   a. 19
   b. 22
   c. 24
   d. 50

6. When N-type germanium and P-type germanium are placed together,
   a. electrons and holes combine at th junction
   b. electrons from the P-type materia combine with holes from the N-typ material to form a potential hill
   c. recombination takes place to neutralize the charges
   d. current flows from the P-type to th N-type material

7. Cutoff current is
   a. emitter current when collecto voltage is zero
   b. base current when collector cur rent is zero
   c. collector current at high-frequenc cutoff
   d. collector current when emitter cur rent is zero

8. Base resistance is equal to 100 ohm emitter resistance 400 ohms, collecto resistance 299.9 K and alpha is equal 0.95. What is the theoretical voltage gai of the transistor?
   a. 570
   b. 600
   c. 750
   d. 1,000

9. Collector current is determined by
   a. collector voltage
   b. forward bias
   c. impurity content
   d. base current

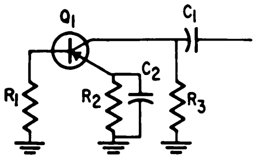
10. A semiconductor has
    a. high conductivity
    b. low resistance
    c. greater conductivity than an insul tor
    d. less conductivity than an insulat

11. Alpha is the ratio of
    a. base current to collector current
    b. collector current to base current
    c. emitter current to collector current
    d. collector current to emitter current

12. To produce a current flow across a PN junction
    a. reverse bias is applied
    b. a very high voltage is required
    c. a negative potential is applied to the N-type material with respect to the P-type material
    d. more holes are required than electrons

13. A characteristic of the semiconductor germanium is that it possesses
    a. 14 electrons distributed in 3 rings
    b. 32 electrons distributed in 4 rings
    c. 3 electrons in its outer ring
    d. 4 valence electrons

14. In the drawing below, R_2
    a. is a biasing resistor
    b. is a current limiting resistor
    c. provides d-c stabilization
    d. is a load resistor



15. The circuit shown in the previous question is a
    a. grounded-emitter amplifier
    b. grounded-base amplifier
    c. ground-collector amplifier
    d. RC-coupled oscillator

In questions 16 through 24, match the item in column A with its related item in column B.

A	B
16. P-type material	a. Requires d-c stabilization
17. N-type material	b. Current gain of a grounded emitter stage
18. PN junction	c. Holes are primary carriers
19. Grounded-base amplifier	d. Increases frequency response
20. Grounded-emitter amplifier	e. I_c/I_e
21. Grounded-collector amplifier	f. Germanium with arsenic impurity
22. Alpha	g. potential barrier
23. Beta	h. No polarity inversion of input signal
24. Tetrode transistor	i. Impedance matching device

25. An electronic method of controlling core permeability is obtained by
    a. decreasing the number of turns of the coil
    b. increasing the number of turns of the coil
    c. using a properly designed magnetic core material
    d. saturating the core with d-c or a-c voltage

26. An advantage of using a three-legged core saturable reactor in preference to using a two-legged one is that
    a. it will eliminate transformer action between the series winding and control winding
    b. there will be more current drawn from the a-c source
    c. there will be more a-c voltage induced into the control windings
    d. it is adaptable only for d-c loads

27. A basic magnetic amplifier consists of a
    a. variable load in series with an a-c source
    b. load and an a-c source in parallel with an inductor
    c. controlled variable inductance in series with an a-c power source and a load
    d. variable inductance in parallel with an a-c power source

28. The inductive reactance of the coil in figure 4-27 (A) will be maximum when the
    a. iron core is fully inserted into the coil
    b. a-c source voltage is maximum positive
    c. iron core is fully retracted from the coil
    d. a-c source voltage is maximum negative

29. The addition of rectifiers in series with the a-c load windings produces
    a. negative feedback
    b. external feedback
    c. internal feedback
    d. degenerative feedback

30. One method of controlling the inductance of a given coil is by
    a. controlling the permeability of the core
    b. increasing the current flow in the coil
    c. increasing the voltage applied to the coil
    d. decreasing the frequency applied to the coil

31. A disadvantage of using the simple magnetic amplifier shown in figure 4-27 (A) lies in the fact that
    a. power requirements are excessive
    b. it is a mechanical device
    c. it has no low frequency limit
    d. it has no high frequency limit

32. How much impedance will a saturated core offer to the applied a-c source voltage?
    a. Maximum
    b. The same as when not saturated
    c. Minimum
    d. Zero

33. When the iron core is fully retracted from the coil (fig. 4-27 (A)), the voltage drop across the output load is
    a. minimum a.c.
    b. zero
    c. maximum d.c.
    d. maximum a.c.

34. An effect of using external positive feedback in magnetic amplifiers is
    a. decreased gain and decreased time of response
    b. increased gain and decreased time of response
    c. increased gain and increased time of response
    d. decreased gain and increased time of response

CHAPTER 5

FUNDAMENTALS OF COMPUTERS

A computer is a device that performs mathematical calculations on input data to yield new and generally more useful results. The first computer, an abacus, was used by the ancient Greeks and Romans. It is a simple kind of manually operated device utilizing sliding beads; and if operated according to definite rules, can perform addition and subtraction. Computers found in use today range in complexity from the mechanical adding machine or slide rule to room size devices commonly called electronic brains.

Airborne computers are used extensively in bombing, navigation, and fire control equipments.

Computer Classification

Computers may be divided into two main classifications; namely, digital and analog.

The digital computer receives problems involving distinct and fixed numerical quantities, and also produces the solution of these problems as distinct and fixed quantities. That is, for a stated problem, the digital computer produces a stated answer. If any factor in the problem is varied, it must then be treated as a new and different problem and recomputed. The digital computer expresses magnitude as a number of digits, and its accuracy is limited only by the number of significant figures provided. Increased accuracy can be obtained by utilizing more significant figures. The basic principles of operation of any digital computer are the same as that of the abacus or hand operated adding machine.

Analog computers are best employed where continually varying solutions are needed for problems whose factors are continually varying. These factors generally are physical quantities, such as velocity, direction, or range, and are represented to the computer by the most convenient means. Such physical quantities are most conveniently represented by degrees of shaft rotation, magnitude or phase of a voltage, or the speed and direction of movement of some mechanical part. The varying instantaneous summation, or solution, of all the computing parts comprises the computer's output.

This output may then be applied as needed, depending on the purpose of the computer. For instance, in a fire control computer, the output positions a gun or rocket sighting reticle in relation to the direction of flight. As the pilot maneuvers to keep an enemy target within the reticle, the guns or rockets are properly aimed. In a bombing computer, the output releases bombs at the proper time. In a navigational computer, the output is used to drive indicators which give the aircraft's position at all times in latitude and longitude. The accuracy of the analog computer is determined by the percentage errors of the devices used, multiplied by the maximum quantity of the input variables.

Computer Types

Computers may be further classified, based on their construction, as follows:

1. Mechanical.
2. Electronic.
3. Electromechanical.

Mechanical computers utilize mechanical quantities to represent the input and output values. They normally contain devices that add, subtract, multiply, or divide.

Electronic computers utilize electrical units, such as voltage amplitude and phase, resistance, electrical pulses, and other electrical units to represent physical quantities. Computers of this type normally contain electronic and magnetic amplifiers, phase detectors, modulators, and demodulators.

Electromechanical computers represent numbers or variables in both electrical and mechanical units. A typical application may employ both electrical and mechanical inputs to a servomechanism and have a mechanical output.

In actual practice, computers used in aircraft will not normally be of any one type, but will contain some features of all types. Their classification is based on the predominant type of computing device found in the equipment.

Basic Principles of Digital Computers

While analog computers use continuous physical quantities (such as voltage) to represent information, digital computers use a series of fixed steps or conditions to represent information.

High-speed automatically sequenced electronic computers include simple arithmetic units which add, subtract, multiply, and divide. More complicated problems, such as differentiation, are reduced to arithmetic solutions. Information is stored in registers or memory units. Each register is identified so that a control system can guide the computer to perform a sequence of operations. Coded information which establishes the program, or routine, for solving a problem is fed into the input unit. Output devices convert computer solutions into readable answers.

Ordinary desk calculators use ten-tooth gears which can be positioned to represent every digit, 0 through 9, of our decimal system. For high-speed computers there is no ideal electronic component which has ten positions. However, vacuum tubes which are on or off (conducting current or not conducting) readily and reliably represent two positions. Fortunately, there is a notation system available, called the binary system, which lends itself to the vacuum-tube computer.

THE BINARY SYSTEM

In the decimal system of notation, quantities are identified by the location of digits to the right or left of a decimal point. The first place to the left is reserved for multiples of ten to the zero power (10^0), the second place for multiples of ten to the first power (10^1), the third place for multiples of ten to the second power, (10^2), and so on. Consider the number 872. This combination of decimal digits actually means $(8 \times 10^2) + (7 \times 10^1) + (2 \times 10^0)$, because 8 is the multiple appearing in the position reserved for 10^2, 7 is the multiple for 10^1, and 2 is the multiple for 10^0. Thus, the quantity 872 may be considered as $(8 \times 100) + (7 \times 10) + (2 \times 1)$, or $800 + 70 + 2$ Essentially, then, the decimal system uses any of ten digits (0 - 9) to represent a quantity by placing one digit in each position away from a point, then summing up the quantity represented by each.

Basically, the same system is used in the binary numbering method. The difference however, is that only two digits (0 or 1) are used, and each position away from a point is reserved for progressive powers of two, instead of ten. The first position to the left is reserved for multiples of two to the zero power (2^0), the second place for multiples o two to the first power (2^1), the third place for two to the second power (2^2), and so on. A binary digit, 0 or 1, will appear in each position. To demonstrate, a binary number wil be converted to a decimal number. Table 5- gives some successive powers of two.

Table 5-1.—Table of powers of two.

$2^0 = 1$	$2^3 = 8$	$2^6 = 64$
$2^1 = 2$	$2^4 = 16$	$2^7 = 128$
$2^2 = 4$	$2^5 = 32$	$2^8 = 256$

Example: Convert the binary quantit 101101 to a decimal number. Since 6 position are occupied, this means that the highest powe of 2 contained in the quantity is 2^5. Multiplying each power of 2 by the multiple appearin in its position, you would perform the following:

$$(1 \times 2^5) + (0 \times 2^4) + (1 \times 2^3) +$$

$$(1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0).$$

Combining:

$$(1 \times 32) + (0 \times 16) + (1 \times 8) +$$

$$(1 \times 4) + (0 \times 2) + (1 \times 1).$$

$$32 + 0 + 8 + 4 + 0 + 1 = 45.$$

Thus, it is determined that the binary number 101101 is the same as the decimal number 45.

To convert a decimal quantity to binary, start by selecting the largest power of 2 that will "fit in" the decimal quantity. To this you add the largest possible successive descending powers of 2 until the decimal under is "filled up." Example: Convert 358 to its binary form. The first largest power of 2 that will "fit" is 2^8, or 256. (This also indicates that binary 358 will be a 9-digit number.) Placing a 1 in the 2^8 position (ninth place) examine the next descending power of 2, or 2^7. It is 128. This is too large, because only 102 is now needed to "fill up" from 256 to 358. A 0 is placed in the 2^7 position. Next, 2^6 (or 64) will "fit," so a 1 is placed in the 2^6 position, leaving a remainder of 38. Continue by placing a 1 in the 2^5 position (or 32). This reduces the remainder to 6. Both 2^4 and 2^3 are too large, so 0's are placed in their positions. When 1's are placed in the 2^2 (4) and 2^1 (2) positions, the number is completed, so a 0 is placed in the 2^0 position. Summing up:

$$(1 \times 2^8) + (0 \times 2^7) + (1 \times 2^6) + (1 \times 2^5) +$$

$$(0 \times 2^4) + (0 \times 2^3) + (1 \times 2^2) + (1 \times 2^1) +$$

$$(0 \times 2^0) = 256 + 0 + 64 + 32 + 0 + 0 + 4 +$$

$$2 + 0 = 358.$$

Writing the number in binary, placing 1's and 0's in their proper places, decimal 358 is thus written as binary 101100110.

It can be seen that the binary system is not as efficient as the decimal, since it takes many more places to represent a given quantity. Its advantage, however, is that there are only two digits. These are easily represented in "machine language." For instance, in an electronic computer, a tube conducting could represent "1," while the same tube not conducting could represent "0." In many electronic computers, it is "positive pulse" or "negative pulse." On a magnetic tape, small polarized areas magnetized north-south would represent "1," while those magnetized south-north would represent "0." On cards, it would be punch or no punch, and so on. The value of a binary digit, as far as the computer is concerned, would generally be determined by where it was placed in the computer. That is, if a moving magnetic tape had 10 parallel channels running its length, the computer would have 10 pickup heads poised across the tape, one over each channel. Each head is sensitive only to one channel. Assume that a north-south magnetized area in the tenth channel was detected by its pickup head and caused a positive pulse somewhere in the computer. Since the pulse originated in the tenth channel, this would mean "1×2^{10}," or 1024, to the computer. If all heads read "1" simultaneously, this would be, to the computer, $2^{10} + 2^9 + 2^8$, etc. and would be the highest number it could "conceive." In this case, such a number is the sum of all the powers of 2, up through the tenth power, (because there are 10 channels) or 2047.

Binary digits are also used as coding to represent intelligence other than numerical quantities. A certain combination of 1's and 0's may represent a letter, name, or object, and so on. The number of different possible combinations depends on the number of digits in the binary symbol. For instance, a 2-digit binary symbol could have only 2^2 (or 4) different combinations: 00, 01, 11, or 10. A 3-digit symbol would have 2^3 (or 8) possible combinations, a 4-digit symbol 2^4 (or 16) combinations, and so on. As an example, if it were desired to represent each letter of the alphabet binarily, the coding symbols must have at least 26 different possible combinations, because there are 26 letters in the alphabet. That is, 5-digit binary symbols would be required in this case, because they would have 2^5 or 32, possible combinations; enough to code each letter of the alphabet.

GENERAL COMPUTER REQUIREMENTS

Before a computer can operate properly and satisfactorily employ some numbering system such as the binary system, it must have the ability to:

1. Remember data presented to it.
2. Make a choice based on previous results.
3. Make long chains of operations in short duration of time.
4. Determine if the answer is correct.
5. Determine when one problem is finished and when to start on another.

In order for the computer to be capable of the foregoing items, the proper information must be given to it. From this point on the computer will determine the answer by logical steps.

INPUT UNIT

All the known data of a problem is injected into the computing system via the input unit. This unit will normally receive data originating from error signals. These errors could be fed directly to the computer so that rapid corrections could be made.

The next job or function of the input unit is that of decoding. The process of decoding information is an important function that must be carried out by the computer. Information received at the computer must be put into a form that is suitable for the operation of other circuits. This decoding is usually accomplished by any of the several types of demodulating circuits.

LOGICAL UNIT

The logical unit is where arithmetical operations of the computer are accomplished. The relay is a basic example of a device that easily notes the conditions of either GO or NO GO. Other units, however, are designed to simulate this action. These components that exhibit two stable positions are generally referred to as gates or gating circuits. The gate, as the name implies, permits or prevents the flow of current in a circuit.

Another important function that takes place in the logical unit is that of counting. In any computation, it is necessary to have a means by which the number of operations may be determined. This is the function of the counter.

The counting function may or may not be a continuous operation in a computing system. The time at which counting takes place depends on the state in which other components of the system are set; that is, it may be necessary to count a certain number of other operations that have taken place before some new operation is to begin.

MEMORY UNIT

A memory unit stores information until it is required for the computation of a problem. The memory unit is actually the backbone of the computer. It is in this portion of the digital computer that rapid advancement has been made. The use of numerous small magnetic cores so arranged that they are capable of storing large numbers of digits, yet physically small enough to be used in airborne equipment, has opened the door to the use of digital computers in a greater number of aviation applications. These core networks are generally referred to as matrixes.

OUTPUT UNIT

After all computations have been completed, there must be some means of presenting the answers to the operator. For example, in an airborne fire control system the results of the computer may be used directly to position the steering error indication on a radar indicator or compute the release point in a bomb director system. Also, in the navigational computer the output unit drives the latitude-longitude indicator.

The technician should bear in mind that the previous discussion was included only as an introduction to the digital type computers. For detailed information on a specific type of computer you should consult the appropriate service manuals. You should also bear in mind that computers being designed and tested at the present time will have many changes and advancements over the basic digital computer designs discussed in this course. Some modern designs incorporate transistors, printed circuits, magnetic core type memory devices, and many other modern components or devices.

EQUATION REARRANGEMENT

Although computers are capable of performing most of the methods of mathematics, many of the computers used in aviation equipments have been designed around equation rearrangement.

Before considering the details of equation rearrangement, consider first why it is used. There are a number of requirements an analog computer must fulfill. Primarily, it must possess sufficient accuracy to solve a problem within the required limits. It must be constructed in a manner whereby it can withstand the stresses of airborne use and require a minimum of maintenance. It is also advantageous from the maintenance standpoint for a computer to use as many similar components as practicable, keeping the number of spare parts to a minimum. Therefore, you may find equipments that have rearranged simple equations from their simplest form to one that is more complicated mathematically for reasons not readily apparent to the technician.

Assume that the following mathematica equation is to be solved:

$$J = \frac{R\, t_f}{R_f}$$

By a simple algebraic process, the equation is rearranged as follows:

$$\frac{R}{J} - \frac{R_f}{t_f} = 0$$

This arrangement of the equation is ideally suited for solving by use of a servomechanism. As you should recall, the servomechanism provides the necessary action to cancel any error signal producing a zero output.

Another example of equation rearrangement involves the use of logarithms. A computer problem may involve the multiplication and division of several quantities. Referring again to the equation

$$J = \frac{R\, t_f}{R_f},$$

it can be rearranged as follows:

$$\log_{10} J = \log_{10} R + \log_{10} t_f - \log_{10} R_f$$

The logarithm of each quantity may be found electronically by the use of specially designed networks. Once the equation has been changed into the logarithmic form, the computing is accomplished by simplified addition and subtraction of the quantities.

Magnetic amplifiers are especially well suited for solutions of this type. The results can be used frequently in the logarithmic form. However, the analog may also be found by use of a network giving an answer to the problem as originally stated.

Implicit Problem Solving

The use of computers to solve complex problems does not always afford direct solution to all parts of the problem. Thus, the solution may be based on indirect or implicit methods.

Implicit problem solving may accomplish subtraction by means of addition, division by means of multiplication, the extraction of a square root by means of squaring, and integration by means of differentiation. A comparison of explicit and implicit methods of problem solving is as follows:

	Explicit	Implicit
Subtraction	$c = a - b$	$c + b = a$
Square root	$c = \sqrt{a}$	$c^2 = a$
Division.	$c = \frac{a}{b}$	$cb = a$

The use of the implicit function technique is found frequently in computers. There are numerous computations for which the implicit method may be more accurate or more convenient, based on the information available to the computer. Servomechanisms and amplifiers utilizing negative and positive feedback are well suited for instrumentation of implicit operations.

REPRESENTATION OF QUANTITY

For the purpose of this chapter, representation of quantity may be defined as that physical quantity used by an analog computer to represent a specific input quantity. Thus, for example, in an aviation fire control computer, a specific quantity, (range from the gun platform to the target aircraft) may be identified with a d-c voltage fed to the analog computer for solution of the problem.

The following list of representations may be encountered in fire control computers:

Mechanical	Electrical
Force	Voltage
Pressure	Current
Torque	Charge
Linear displacement	Impedance
Angular rotation	Frequency
Linear velocity	Phase
Angular velocity	
Linear acceleration	
Angular acceleration	

Table 5-2 gives some advantages and disadvantages of the two general types of representation. Regardless of the apparent advantages some methods of representation may have, all methods are found in airborne computers.

IDENTITY OPERATIONS

For the purpose of this chapter, an identity operation may be defined as any operation that

Table 5-2.—Comparison of mechanical and electrical methods of representation.

Mechanical		Electrical	
Advantages	Disadvantages	Advantages	Disadvantages
Simpler and easier to understand. Few adjustments. Contain no electronic components subject to failure.	Subject to friction and wear. Requires precision components.	Flexibility. Replacements are normally standard parts. Accuracy. Weight. Speed of response.	Electronic parts failures. Components may change value causing drift.

does not change the mathematical quantity represented. Examples of identity operations are changes in scale factor, voltage level, impedance, and data representation.

Change in Scale Factor

Before discussing a change of scale factor, it will first be defined. In an analog computer, the scale factor is the ratio of the analog unit to the equation unit. Thus,

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units (physical)}}$$

Any change in analog units without a corresponding change in equation units will result in a change in scale factor. To illustrate this, consider the following example:

A 10-volt signal is selected to represent a range of 1,000 yards.

$$\text{scale factor} = \frac{+10 \text{ volts}}{1{,}000 \text{ yards}} = 0.01$$

If the 10-volt signal is fed through a d-c amplifier having a voltage gain of 10, the analog unit is now equal to 100 volts. The scale factor is:

$$\text{scale factor} = \frac{+100 \text{ volts}}{1{,}000 \text{ yards}} = 0.1$$

Thus, the scale factor was changed by the action of the amplifier.

Change of Voltage Level

Computers, such as those utilizing addition and subtraction, most frequently change or shift the voltage level or reference to that level usable by subsequent components or units. A possible example of a shift in voltage level is found in direct-coupled amplifiers where the equipment is limited by the output of the d-c supply for the amplifier.

Change of Impedance

A change in output impedance may be required to match the various sections of a computer. This may be accomplished by the use of networks, and in some cases the use of cathode followers or other amplifiers employing feedback.

Change of Scale

Change of scale is accomplished by multiplication of the data by a fixed quantity. When the multiplier is less than one, simple networks of resistance, capacitance, or inductance may be used. When the constant of multiplication is greater than one, amplifiers whose gain has been accurately calibrated may be used.

Basic Principles of Analog Computers

A computer is a device for instrumentation of a mathematical problem. Therefore, all computers, regardless of type, perform some mathematical functions in solving their problem. The more complex analog computers used in aviation equipments perform many mathematical functions, many of which are performed simultaneously. In this section some of the basic principles employed in complex analog computers will be discussed. It should be realized that many of the manipulations to be discussed may result in the same end product. However, in order to solve a problem with sufficient accuracy in a minimum of time, a computer may employ several methods to solve equations that are similar to one another.

Computing devices have been divided into three groups; namely, linear functions, nonlinear functions, and calculus. Following this the problems involved in grouping the devices to perform more complex problem solving is discussed. The technician should keep in mind that a discussion of this type will be valuable in understanding why some computers approa seemingly simple problems in a compl manner.

Linear Functions

A linear function in mathematics is one that can be shown by straight lines on a graph. Linear functions include those functions that involve summation (addition and subtraction), multiplication, and division, but not those that involve squares, square roots, trigonometric functions, and the like.

SUMMATION

The process of summation can be accomplished with electrical, mechanical, or electromechanical devices. Voltages are added, motions are added, or voltages and motions may be combined to give an output proportional to their inputs.

Electrical Summation

To simplify the presentation, both electrical and electronic summing devices will be discussed under this heading. The first device will be the series circuit in which the output voltage E_o is simply the series addition of the input voltages E_1 and E_2.

$$E_o = E_1 + E_2 \qquad (1)$$

Only one of the input voltages can be grounded. Any others must be isolated from the ground. This is illustrated in figure 5-1.

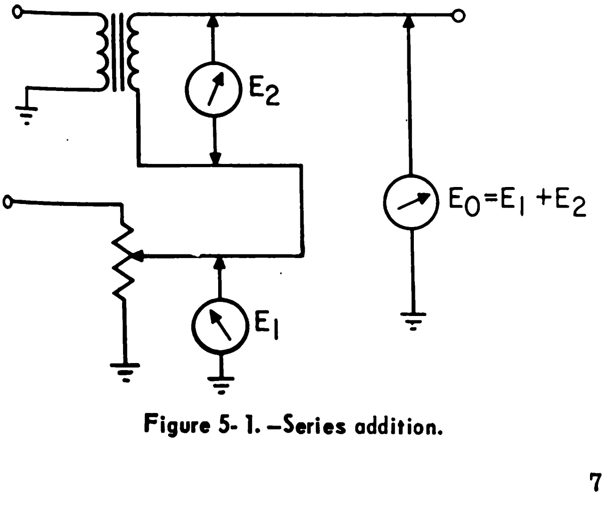


Figure 5- 1.—Series addition.

Note that the secondary of the transform is ungrounded, while the voltage of E_1 is fr a grounded source. Isolating transforme must be carefully designed to minimize capa ity coupling from primary to secondary wir ing, which would cause phase shift variatio

Series adding is primarily used when vo age sources are inductive units, such as sy chros, tachometers, resolvers, etc., alrea isolated from ground. Series summation also used when the attenuation of paral summation networks cannot be tolerated.

When subtracting two a-c voltages by t method, they should be 180 degrees out phase for correct results. Combining voltag that are not in phase or 180 degrees out phase results in a quadrature voltage and co sequently an error in the output.

If d-c voltages are to be added in seri transformers cannot be used and a separ d-c power supply is required for each te or input to obtain isolated sources of volta

It should be remembered that the meth presented in this chapter are basic and ma variations of these methods will be found equipments.

A parallel resistance network can also used to electrically produce the algebraic s of several input voltages. Voltages E_1 and are connected in series with two resist R_1 and R_2 and terminated at a common ju tion as shown in figure 5-2. The voltage is not the actual sum of the input voltages, is proportional to that sum.

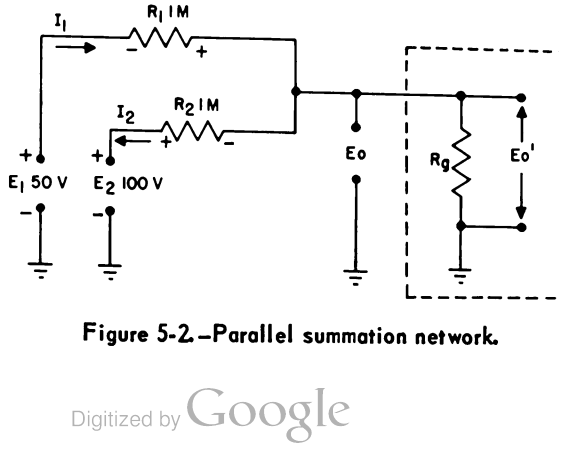


Figure 5-2.—Parallel summation network.

Using the values given in figure 5-2, now prove that the output voltage E_o is proportional to the inputs. If the voltage E_o feeds into an infinite impedance, there will be no load current. The circuit may now be considered as a series circuit, with

$$I_1 = I_2 \qquad (2)$$

Then, since all branches are parallel,

$$E_1 + I_1R_1 = E_2 - I_2R_2 = E_o \qquad (3)$$

Solving the currents in each part of equation (3) and substituting the results into equation (2),

$$\frac{E_o - E_1}{R_1} - \frac{E_2 - E_o}{R_2} = 0 \qquad (4)$$

Solving equation (4) for E_o,

$$E_o = \frac{\frac{E_1}{R_1} + \frac{E_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2}} \qquad (5)$$

or, by further simplification,

$$E_o = \frac{R_2E_1 + R_1E_2}{R_2 + R_1} \qquad (6)$$

Thus, the voltage E_o has been solved for in terms of the sum of the two input voltages and their respective series resistors.

The voltage E_o was solved for above by assuming a very high impedance load. If a grid resistor R_g is included, the voltage E_o is determined by:

$$E_o' = E_o \cdot \frac{R_g}{\frac{R_1\ R_2}{R_1 + R_2} + R_g}$$

As pointed out previously, the voltage output is not the actual sum of the input voltages, but is proportional to that sum. The following example illustrates this proportionality:

E_1 = 50 volts $\qquad E_2$ = 100 volts

R_1 = 1 megohm $\qquad R_2$ = 1 megohm

Then, using equation (5),

$$E_o = \frac{\frac{50}{1 \times 10^6} + \frac{100}{1 \times 10^6}}{\frac{1}{1 \times 10^6} + \frac{1}{1 \times 10^6}}$$

$$E_o = \frac{150}{2} = 75 \text{ volts}$$

If E_o were the actual sum of the input voltages, the voltage output would be 150 volts. However, this difference in actual sum and proportional voltage can be compensated for by a change in scale factor.

When a difference between two terms is required (subtraction), a negative voltage is used to represent the quantity being subtracted (the subtrahend). Both the negative and positive voltages are fed to the parallel resistance network as previously discussed.

Scale Factor

Although addition has been explained as a summation of voltages, the computer's real job is to add physical units, such as feet per second or degrees per minute. The proper application of scale factors makes the addition of physical units of an equation possible.

$$\text{Physical or equation units} = \frac{\text{Analog units}}{\text{Scale factor}}$$

When the physical inputs to the analog computer are represented by voltages, the final solution in the proper units can be found only by dividing the summed voltages by the output scale factor. If the voltages E_1 and E_2 in figure 5-3 were chosen to represent 1,000 feet each, the scale factor for the input voltages would be 1 volt per 10 feet and should be written as $\frac{1 \text{ volt}}{10 \text{ feet}}$.

If the output physical units are to equal the sum of the input physical units, the scale factor at the output must be $\frac{1 \text{ volt}}{20 \text{ feet}}$. By using the transformation formula, the sum of the physical units is

$$\frac{100 \text{ volts}}{\frac{1 \text{ volt}}{20 \text{ feet}}} = 2{,}000 \text{ feet.}$$

In the examples discussed previously the input scale factors were identical. Consider the operation of the summing circuit shown in

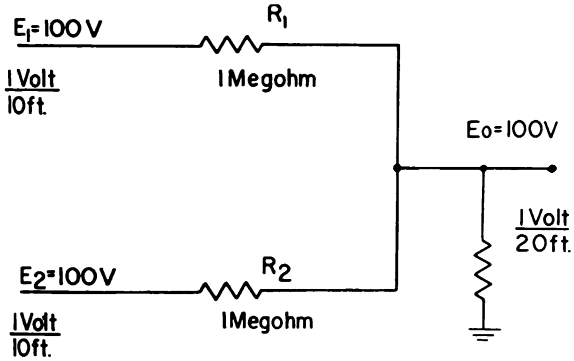


Figure 5-3.—Scale factors assigned to parallel resistor summation networks.

figure 5-4 if the input scale factors are different. In the equation $D_t = D_1 + D_2$, D_1 has a scale factor of $\frac{1 \text{ volt}}{10 \text{ ft.}}$ and D_2 is represented by the scale factor $\frac{1 \text{ volt}}{5 \text{ ft.}}$. Since the physical units per volt of the scale factors must add directly, the output scale factor is $\frac{1 \text{ volt}}{15 \text{ ft.}}$. From the example in figure 5-4 the correct answer for D_t is 2,000 feet. What values of R_1 and R_2 will supply the answer if the analog unit at the output is known and the output scale factor is known? The analog unit is obtained by substituting in the following formula:

$$\text{Analog unit} = \text{Equation unit} \times \text{Scale factor}$$

$$= 2{,}000 \text{ ft.} \times \frac{1 \text{ volt}}{15 \text{ ft.}}$$

$$= 133 \text{ volts}$$

Referring to equation (6), it is apparent that R_1 cannot equal R_2 as in the previous example. It is permissible to select one resistance value arbitrarily, consequently R_1 may be set equal to 100,000 ohms, a typical value. Substituting known values in equation (6) and solving for R_2:

$$133\text{V} = \frac{R_2 \times 100 + 100{,}000 \times 200}{100{,}000 + R_2}$$

$$R_2 = 200{,}000 \text{ ohms}$$

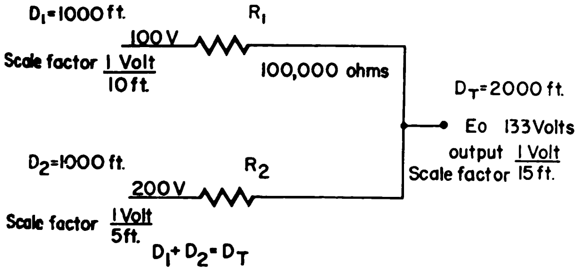


Figure 5-4.—Addition with unequal scale factors.

Generally you will not be expected to compute component sizes or scale factors. However, it is of the utmost importance that you have a thorough understanding of scale factors in order that you may understand what is being accomplished in each stage of a computer and also how it is being accomplished.

In analog computers it is not always possible to apply the output of parallel resistor summation networks directly to subsequent circuits without getting nonlinear results because of loading. Loading is avoided by using an amplifier with a high-impedance input and a low-impedance output between the summation network output and the succeeding computer component. Either a cathode follower or an isolation amplifier can be used. For a detailed discussion on their operation, refer to *Basic Electronics*, NavPers 10087.

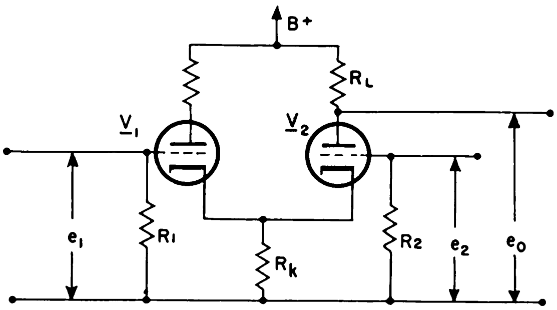


Figure 5-5.—A typical common cathode difference amplifier.

Electron tube circuits may also be used for the summing operation in analog computers. A typical difference amplifier is illustrated in figure 5-5. The input voltages, which are applied directly to the grids of the triodes, may be either negative or positive and need not be from an isolated source. The output voltage (e_o) is developed across the plate load resistor (R_L) of V_2 and is equal to

$$e_o = \frac{\mu R_L}{R_L + 2r_p} (e_1 - e_2)$$

It is assumed that V_1 and V_2 will have equal values for μ and within the tolerances required.

The output voltage is a proportional sum and is determined by the gain of the stage which is, in turn, determined by the circuit components. It should be remembered that a proportional sum output requires a change in scale factor as discussed previously. A typical adding circuit is shown in (A) of figure 5-6. It also produces a proportional sum which is the sum of the individual tube's cathode current multiplied by the resistance of R_k. A variation of this adding circuit is shown in (B) of figure 5-6. This circuit offers an advantage of having small interaction between its inputs due to the large impedance of each stage.

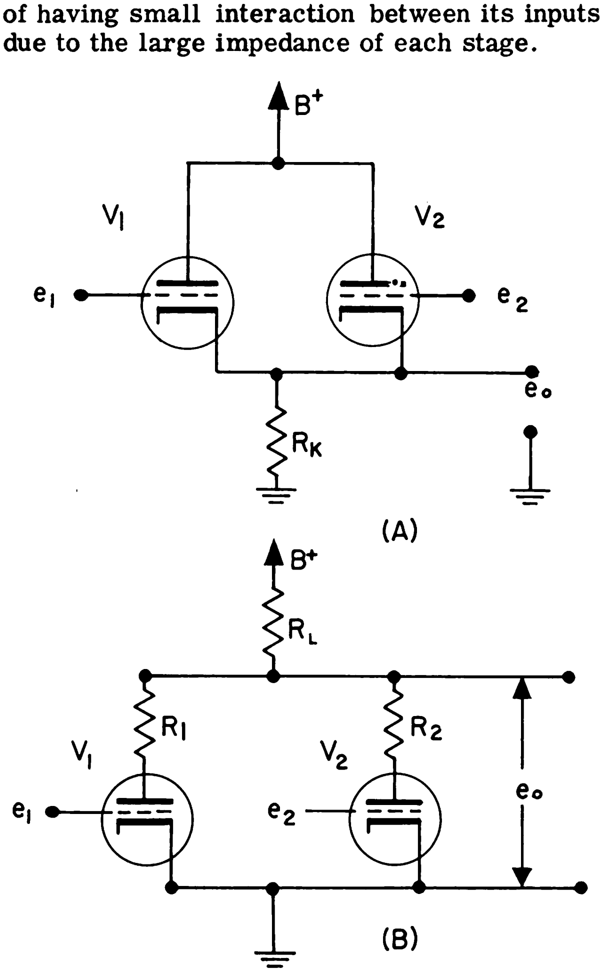


Figure 5-6.—Typical adding circuit.

Mechanical Summation

The device most commonly used for mechanical summation is the differential, of which there are several types. Basically, the differential adds the revolutions of two shafts or subtracts the revolutions of one shaft from that of another shaft. The answer is given in the form of shaft rotations of a third shaft equivalent to one-half the sum or difference of the two inputs as the case may be. (Refer to fig. 5-7.)

Input shaft A passes through gear D, using it only as a bearing, but connects to and drives gear E. Gear E then drives gears G and F, transmitting the rotation of shaft A ($\theta 1$) to shaft C ($\theta 3$). Shaft B drives gear D, which is fixed to the outer cage. The cage, in turn, moves idler gear G in a circular orbit. If gear E (shaft A) is held stationary, all of shaft B's rotation will be transmitted to shaft C by idler gear G. Any rotation of shaft A will either add to or subtract from the rotation of shaft B, depending on direction of rotation.

Electromechanical Summation

If the inputs or outputs of a summing operation cannot be physically brought together, synchro system may be used. A chain of thre synchro units consisting of a synchro transmitter, a synchro differential transmitter, an a synchro receiver adds or subtracts shaf rotations. If an output voltage rather than shaft rotation is needed, the synchro receive can be replaced with a synchro control transformer. Gear ratios may be added betwee the input shaft and the differential transmitte rotor to introduce coefficients. An exampl formula might be as follows:

$$\theta_o = \theta_1 \pm K\theta_2$$

The accuracy of a synchro summing system may be increased by using a two-spee synchro transmission system. For a discussion on the construction and theory of operation of synchro systems, refer to *Basi Electricity*, NavPers 10086.

MULTIPLICATION

Multiplication is one of the mathematic operations which must be performed in a con puter. It may be performed electronically electron tube amplifiers or by magnetic ampl fiers, electromechanically by potentiometer and mechanically by devices called multiplier

Electronic Multiplication

A variety of multiplying circuits have be devised employing electronic amplifier

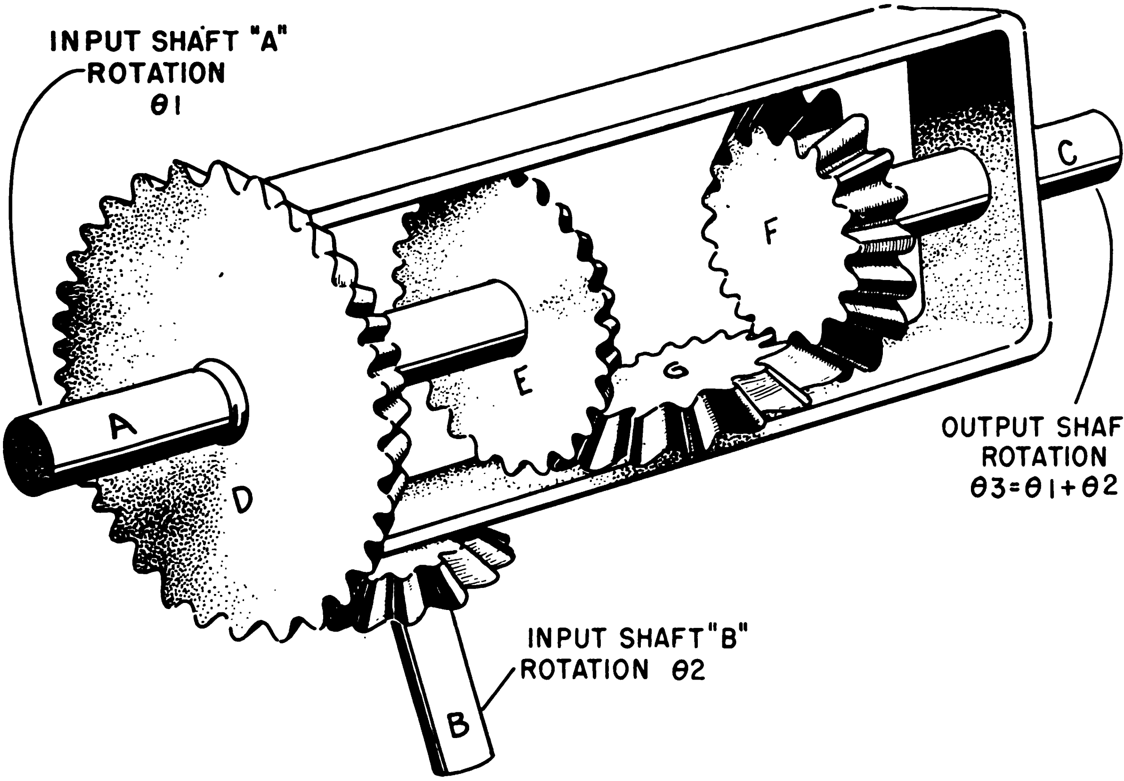


Figure 5-7.—Mechanical adder differential.

However, every linear amplifier is a multiplier. It solves the equation

$$e_o = \mu e_g$$

which is identical to

$$y = kx$$

The grid signal e_g is multiplied by the tube amplification μ to give the product e_o. A typical amplifier as shown in figure 5-8 may be used for this purpose.

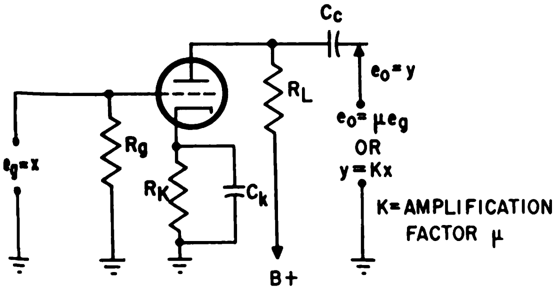


Figure 5-8.—Linear amplifier as a multiplier.

The available output voltage depends on the relation between the tube's internal impedance, r_p, and the load resistance, R_L. The actual output voltage in figure 5-8 is

$$e_o = \mu e_g \frac{R_L}{r_p + R_L}$$

Where R_L is very large compared with r_p, the simpler formula $e_o = \mu e_g$ gives a good approximation of the output voltage.

Theoretically, the input signal voltage would be amplified by the same factor under all conditions. However, the transconductance, amplification factor, and plate resistance of the tube will vary with the applied voltage, and hence cause the circuit amplification to vary with the supply voltage. Therefore, d-c analog computers frequently employ negative feedback circuits. When a part of the output voltage of an amplifier is fed back to its input in such a manner as to oppose the input signal, it is called negative feedback. Feedback in amplifiers is discussed in detail in *Basic Electronics*, NavPers 10087.

Utilizing sufficient amount of negative feedback and a high gain amplifier will allow the actual gain of the circuit to be practically a function of feedback and almost independent of tube variations. A typical amplifier circuit utilizing negative feedback is illustrated in figure 5-9.

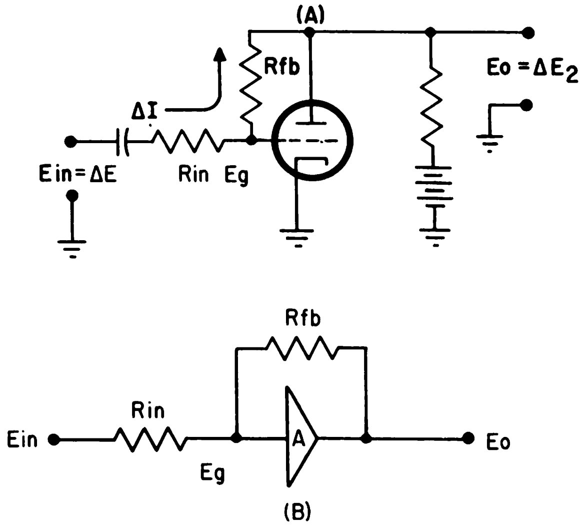


Figure 5-9.—Schematic of d-c amplifier with negative feedback.

Electron tube amplifiers are also capable of solving multiplication problems involving two variables as represented by the equation

$$e_o = kxy$$

Figure 5-10 illustrates a typical triode multiplication circuit. One variable input is applied as grid bias (preferably a d-c voltage) which establishes the gain of the stage (e_2). The other variable (e_1) input is applied directly to the grid of the tube.

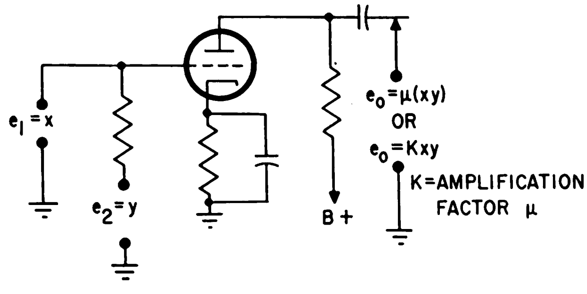


Figure 5-10.—Triode tube used as a multiplier involving two variables.

The output is a proportional quantity equal to the grid signal modified by the gain which is proportional to the variable bias voltage. This method is limited in scope and has limited accuracy due to variations in tube characteristics, contact potential, plate and filament supply changes, etc.

An improved multiplying circuit is shown in (A) of figure 5-11. Its operation is similar to the circuit shown in figure 5-10 except it employs the use of two separate grids. The voltage gain of the stage is controlled by the voltage on grid 3 as shown by the curve illustrated in (B) of figure 5-11. The gain of the amplifier is proportional to the voltage e_3 and may be expressed as follows:

$$A = k\,e_3$$

If the output voltage e_o is directly proportional to e_1, the input signal is

$$e_o = A\,e_1$$

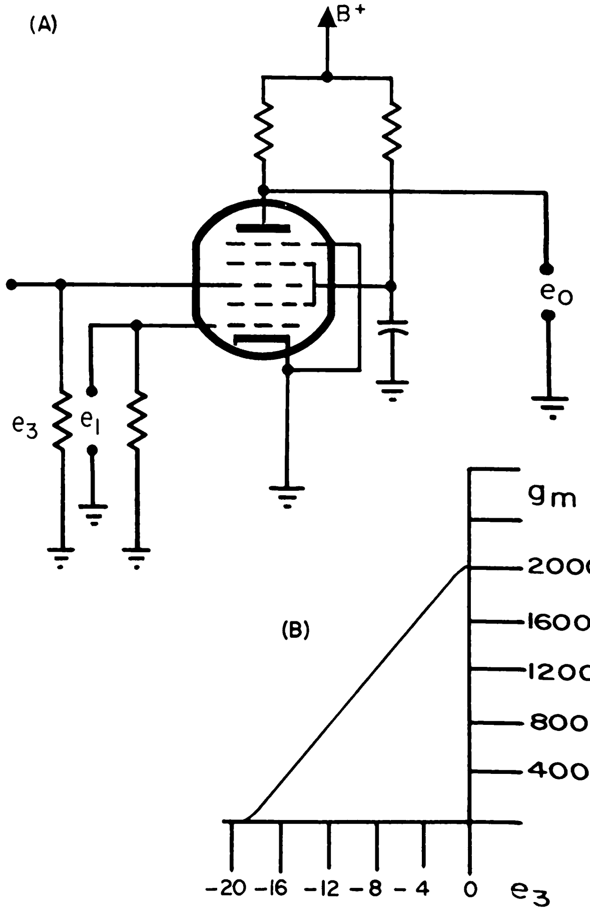


Figure 5-11.—Multielectrode tube used as a multiplier.

Substituting for *A*,

$$e_o = k\, e_1\, e_3$$

The output is a proportional quantity as indicated by the constant *k*.

Magnetic amplifiers may also be used to multiply one factor by another. The saturable core reactor element in magnetic amplifiers makes the magnetic amplifier easily adapted for multiplying operations. Its amplification can be made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations.

Electromechanical Multiplication

Some of the electromechanical devices used for multiplication are potentiometers, synchros, and precision variable autotransformers. (Usually called by trade name: Variac.)

Precision potentiometers are frequently used as multipliers in computing equipment because they are accurate, rugged, simply constructed and inexpensive. They are equally well suited for a-c or d-c applications. Figure 5-12 illustrates a typical potentiometer type multiplier circuit.

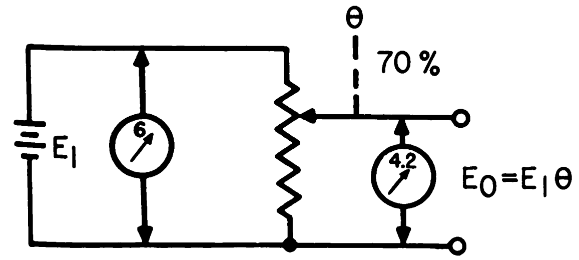


Figure 5-12.—Potentiometer type multiplier.

The voltage occurring between the wiper and one end of the potentiometer is in reality the product of multiplying two quantities:

$$E_o = E_{in}\, \theta$$

One quantity is the voltage impressed across the resistor element, and the other is the position of the wiper. When E_{in} is 100 volts and θ is 100 percent, E_o is equal to 100 volts. If θ is 50 percent of full shaft rotation, E_o is equal to 50 volts.

A grounded center tap on the potentiometer winding permits either positive or negative output depending upon the polarity of the input voltage and the position of the wiper shaft. The primary disadvantage of the potentiometer type multiplier is that a quantity cannot be multiplied by a factor greater than one.

Autotransformer multiplication is identical with potentiometer multiplication except that the input voltage must be a.c. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low d-c resistance of the winding.

The low output impedance of the variable autotransformer permits it to be connected directly to other transformers, potentiometers or inductive resolvers, without intervening isolation amplifiers.

Mechanical Multipliers

These multipliers usually produce a solution through the use of similar triangles. (See *Mathematics*, NavPers 10069-A.) There are four types of multipliers in use—screw, rack, sector, and cam types.

Screw Type

The screw multiplier, shown in figure 5-13, has two inputs and one output. The inputs are shaft values which position the input slide and input rack. The output appears at the output rack which positions the output shaft. Thus the output shaft value is always proportional to the product of the two inputs.

One input gearing is connected to two long screws. These screws pass through the threaded sleeve-like ends of the slotted input slide. As the input gears to the screws are rotated, the two screws turn to position the slide left or right. At the same time, the other input positions the input rack up or down, moving the slotted pivot arm around the stationary pin.

The multiplier pin is mounted in the slots of the input slide, pivot arms, and output rack, connecting all three where the slots cross. As the multiplier pin moves with the input slide and pivot arm, it positions the output rack and gear.

Now, consider the multiplier in the zero position shown in figure 5-14. If only the screws are rotated the input slide moves to the right, but it will not affect the output rack. Similarly, if only the input rack is moved up

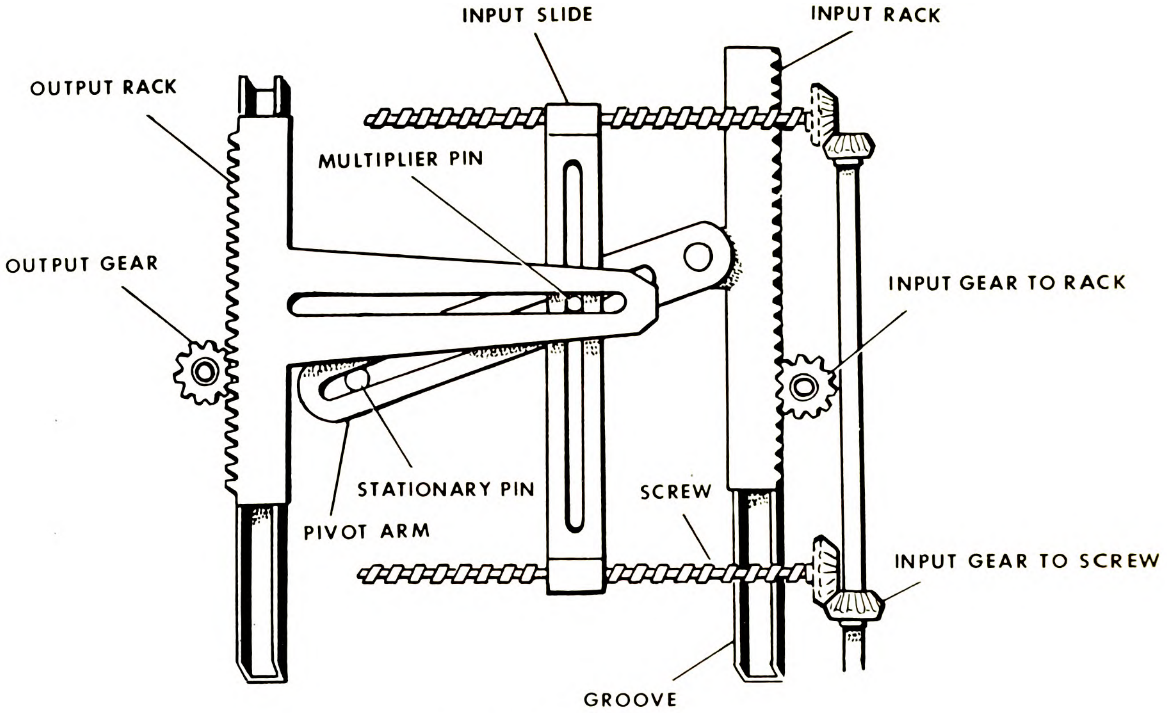


Figure 5-13.—Screw type multiplier.

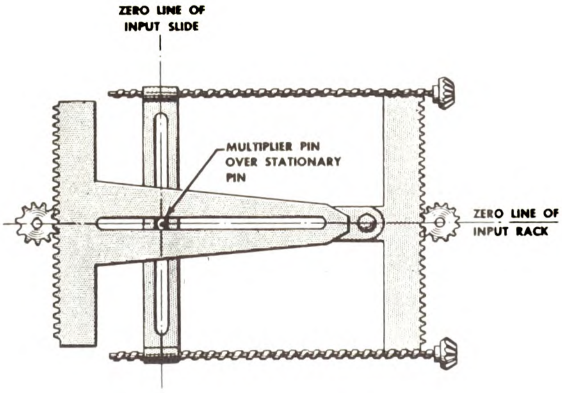


Figure 5-14.—Screw type multiplier in zero position.

or down from the zero position, the output rack will be unaffected. This is a reasonable result since any number multiplied by zero is equal to zero.

From this it can be concluded that both inputs must be removed from the zero position for an output. Such a condition is shown in figure 5-15. Notice the triangle superimposed on the device. The value *a* represents the amount of rack input. The value *b* represents the amount of slide input. *K* is a fixed distance, since the multiplier pin cannot move and th input rack travels in a mechanical guide rai

Because the angles are equal, the triangle are similar. Thus the value of x can be determined if the other values are known.

$$\text{(Actually, } x = \frac{ba}{k}.\text{)}$$

This equation shows that the output (x) i always proportional to the product of the tw inputs. The constant value (k) can be compensated for by the proper choice of input a output gearing for the multiplier. These mu tipliers can also determine the product negative values.

Rack Type

The rack type multiplier in figure 5- performs the same task as the screw ty multiplier. The differences are that (1) t screw input has been replaced with an inp rack, and (2) the output rack is placed on t same side as the second input rack. Like t screw type the rack multiplier can hand both positive and negative values.

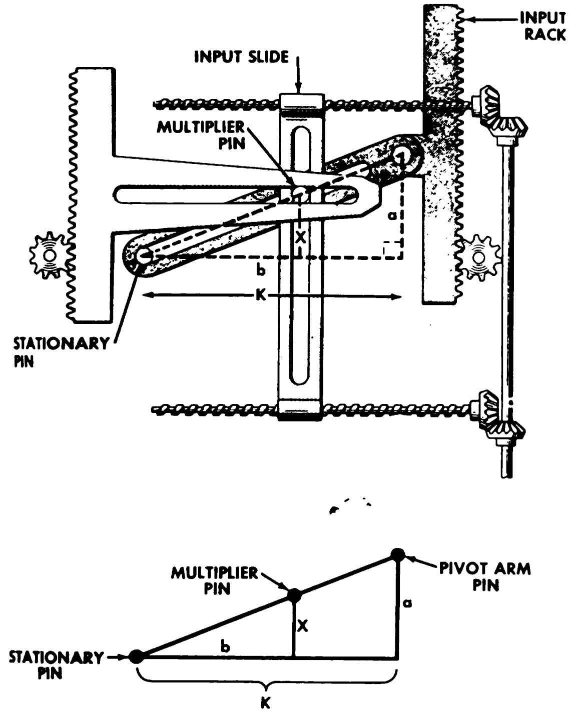


Figure 5-15.—Screw type multiplier—multiplying positive values.

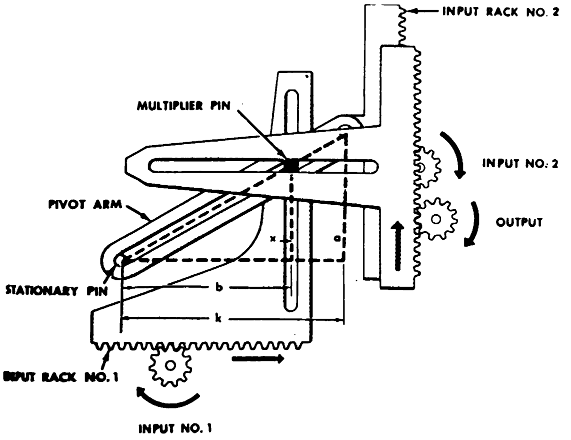


Figure 5-16.—Rack type multiplier—multiplying positive values.

Notice in figure 5-16 that the rack type also mploys similar triangles. The output is ways proportional to the product of the two uts. The output can be equal to the product the use of the proper gear ratios. Zeroing rack type multiplier is similar to the ad- tment of the screw type multiplier. As h most mechanical computing mechanisms, djusting the rack type is largely the application of common sense and mathematical principles.

Sector Type

Although different in construction, the sector type also employs triangles for the multiplication of the two inputs. A sector type multiplier is shown in figure 5-17.

One input positions the input sector arm and the other input turns a large screw that is mounted on the input sector arm. The bevel gear turns this lead screw through a universal joint. The use of the universal joint permits the input to drive the lead screw as the sector arm changes its angular position. Notice that the lead screw drives the multiplier pin up and down the sector arm. Thus the position of the input sector arm and the position of the multiplier on the lead screw represents the two values to be multiplied.

One end of the parallel arm in figure 5-17 is pivoted on the output sector arm by the connecting pin. The other end is mounted on the radius arm. The multiplier pin moves in the slot in the parallel arm. You can see why the slotted piece which always moves parallel to a line through the three lower pivot pins, is called a parallel arm. Since the slot is at right angles to the parallel arm, it is always perpendicular to the base line.

A study of figure 5-17 will reveal how the output section arm will move in response to either the movement of the input sector or the movement of the multiplier pin on the sector arm. Of course, if either of the input quantities is zero, movement of the other input will not produce any output.

One zero input occurs when the lead screw on the input sector arm is parallel to the slot in the parallel arm. The other zero input occurs when the multiplier pin is directly above the pivot point of the input sector arm. Movement of the multiplier pin when the screw is vertical will not affect the parallel arm and therefore the output sector. Similarly movement of the input sector when the multiplier pin is at the pivot point will not affect the parallel arm and output sector.

Consider now how the combination of the two inputs has positioned the sector arm and multiplier pin in figure 5-18. Two right triangles have been formed. Side *c* is the same length in both triangles. *K* is the hypotenuse in the left triangle while *a* is the hypotenuse in the right triangle.

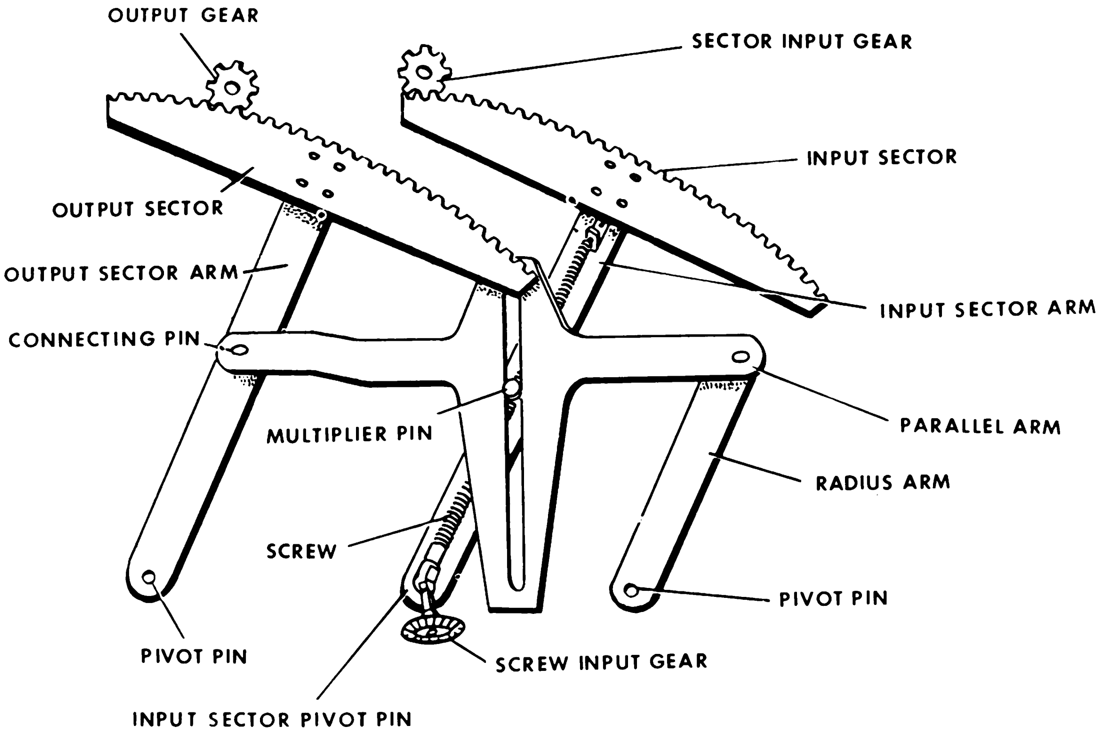


Figure 5-17.—Sector type multiplier.

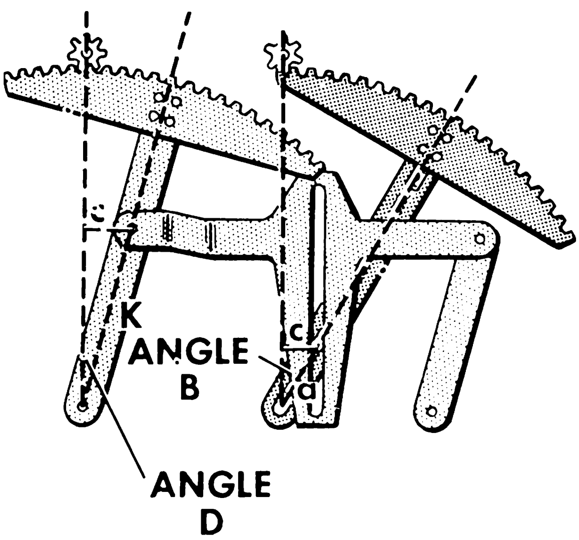


Figure 5-18.—Multiplying with the sector type multiplier.

Based on the fact that *c* is the same length in both triangles it can be shown that angle *D* in radians is equal to *a* times angle *B* in radians divided by *k*. Since these angles are expressed in radians, the radian value of angles *B* and *D*, which measures the motion of th sectors, can now be substituted for the angle in each case. Thus, output *D* is the product c the two inputs divided by the constant *k*. Tl output is proportional to the product of the tw inputs.

A study of figure 5-17 shows that negati quantities can be introduced on the input sector. However, the multiplier pin position ru only from zero to positive values as it cann run below the pivot point of the input secto arm. While the sector type multiplier c handle both positive and negative inputs on t input sector arm the input to the lead scre must always be a positive quantity.

Cam Type

The cam computing multiplier is a du operation device. It computes a function one value on a cam and multiplies that fun tion by a second value. It is a combination a cam and rack type multiplier.

A single cam computing multiplier is sho in figure 5-19. Notice it is like the rack ty multiplier except that one of the inputs is p sitioned by a cam instead of a rack. The c

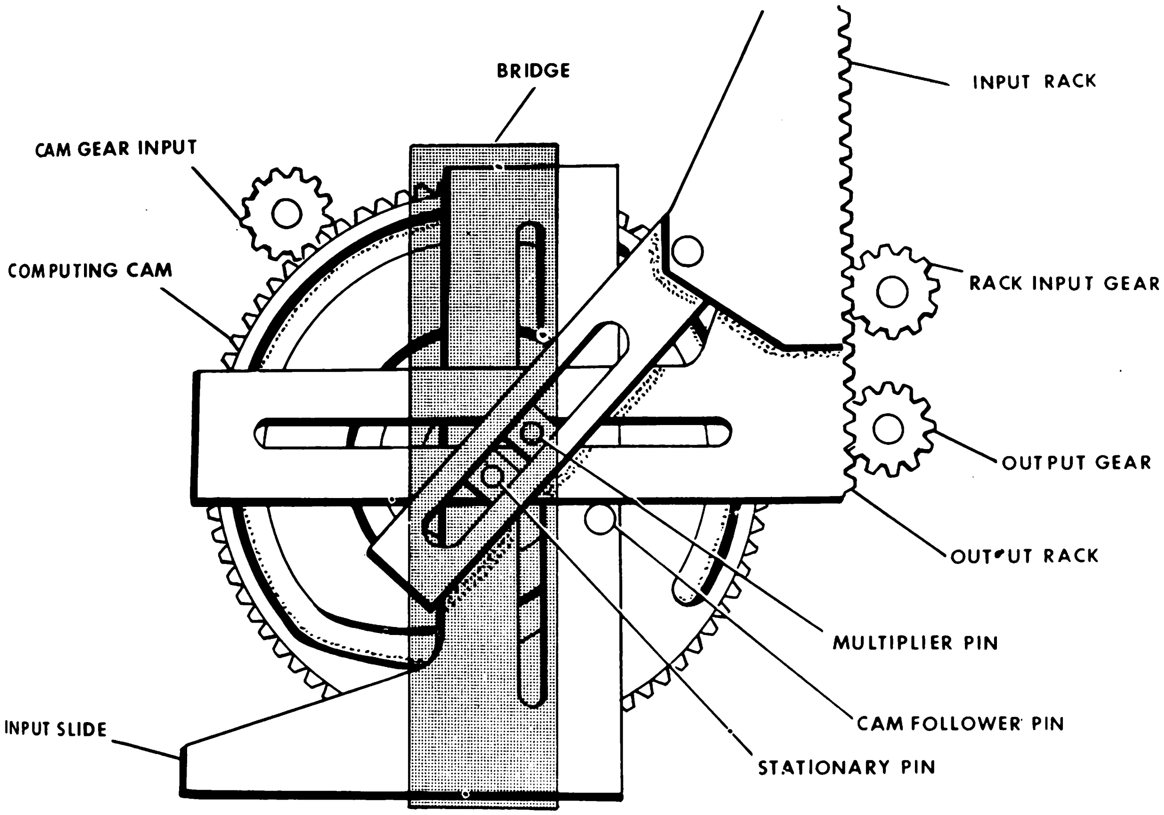


Figure 5-19.—Single cam computing multiplier.

follower pin is mounted directly on the multiplier input slide. This cam may be cut to compute any desired function of the cam input.

One input drives the input rack through the rack input gear. The other input drives the cam directly. The cam positions the input slide according to the function for which the cam was cut. Thus the cam output becomes the slide input. The position of the output rack represents a value which is proportional to the product of the cam output and the rack input, just as in the rack type multiplier.

A two-cam computing multiplier computes the function of both inputs and multiplies these functions together. The output is proportional o the product of the functions of the two inputs.

DIVISION

Instrumentation of division problems in an xplicit form is generally difficult to perform. wever, division can be accomplished by king the reciprocal of the divisor and multi- ying it by the dividend. This allows the use less complex multiplication devices.

Electromechanical Division

A rheostat, or a potentiometer connected as a rheostat in a voltage divider circuit provides a means of dividing a voltage by a shaft position. The voltage divider is an extremely simple method of dividing. The input voltage is applied to one end of the rheostat, and the second input is the shaft position of the rheostat. Figure 5-20 illustrates the operation of a divider network.

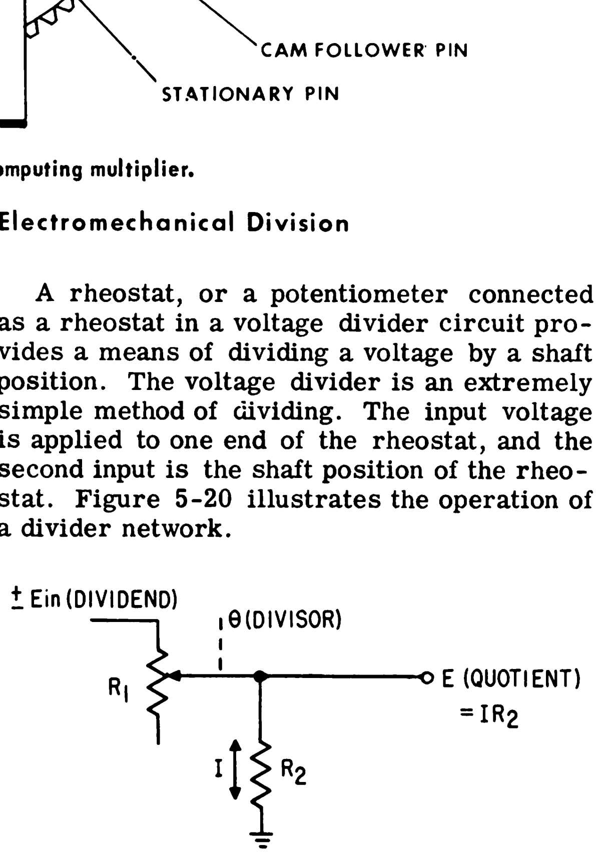


Figure 5-20.—Rheostat divider network.

Since the shaft position of the movable contact controls the series resistance, current is a quotient of voltage divided by the circuit resistance. The quotient can be obtained as a voltage across the fixed resistor R_2, in series with the rheostat. As in any analog system of division, the divisor cannot go to zero since the quotient would then become infinity. R_2 limits the current, and its value establishes the range of the divisor.

A voltage E_{in} is made proportional to one input and the resistance $R_1 + R_2$ is proportional to the second input.

The current

$$I = \frac{E_{in}}{R_1 + R_2}$$

The output voltage

$$E_o = \frac{E_{in}}{R_1 + R_2} R_2$$

or

$$\frac{E_o}{R_2} = \frac{E_{in}}{R_1 + R_2}$$

Substituting K for the constant value of R_2, and θ for the variable R_1:

$$\frac{E_o}{K} = \frac{E_{in}}{\theta + K}$$

The term K affects E_o only as a scale factor change. It affects θ only as a shift in value. Consider as an example the equation for determining angular velocity $\omega = \frac{S}{D}$ radians per second where S is linear velocity in feet per second; D is slant range with limits from 600 to 6,000 feet.

The value of R_2 represents the minimum range of 600 feet and $R_1 + R_2$ represents 6,000 feet. Therefore,

$$\frac{R_1}{R_1 + R_2} = \frac{600}{6{,}000} \text{ or } R_1 = 9R_2$$

A value for R_2 is selected which will produce reasonable current limits over the range of E_{in}. If E_{in} has a range from 0 ± 100 volts and the maximum current which may be draw
is 10 ma., R_2 becomes 10,000 ohms. R_1 wi
then vary from 0 to 90,000 ohms as D goe
from 600 to 6,000 feet. E_o at maximum spe
and minimum range will be as follows:

$$\frac{100 \times 10{,}000}{10{,}000} = 100 \text{ volts}$$

When D = 6,000 feet, maximum speed w
produce an angular velocity output repr
sented by an output voltage E_o of:

$$\frac{100 \times 10{,}000}{90{,}000 + 10{,}000} = 10 \text{ volts}$$

Since R_1 cannot have a negative value, th
method is only suitable when the divisor h
the same polarity at all times.

Servomechanisms are often used for i
plicit division in computers. Division is us
ally represented by the equation

$$x = \frac{y}{z}$$

However, in order to utilize a servomechanis
the equation is rearranged as follows:

$$y - xz = 0$$

The instrumentation of the equation is sho
in figure 5-21.

The system has two electrical inputs, t
amplitude and polarity of each are determin
in other units. The voltage y is fed directly
the error detector while the voltage z is mu
tiplied by the shaft position x, with the produ
xz being fed to the error detector for co
parison with the input y. As in any servo sy
tem, the error voltage difference between
and y drives the servomotor in the directi
that will cancel this error voltage giving
zero output. The output is in terms of n
shaft position.

Electronic Dividers

Electronic division can be performed
inserting a vacuum tube in place of the va
able resistor in a rheostat divider netwo
The plate resistance of the tube is varied
the voltage applied to the control grid. Figu
5-22 illustrates the circuit of an electro

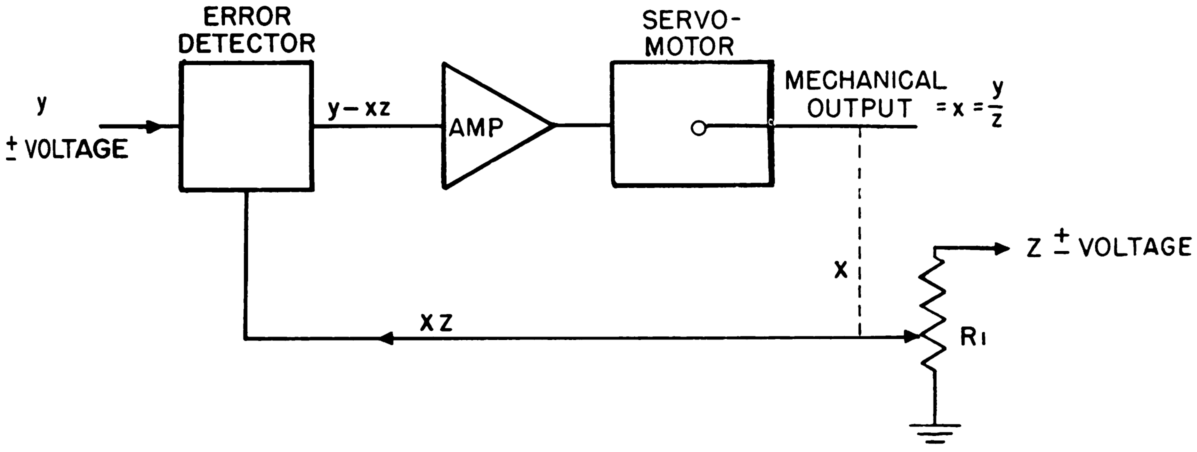


Figure 5-21.—Division with a servomechanism.

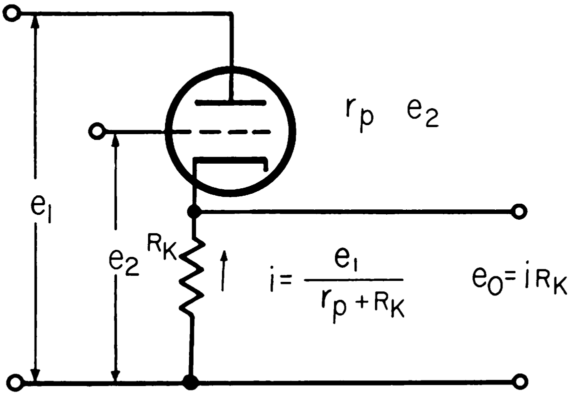


Figure 5-22.—Electronic divider circuit.

divider. The cathode resistor performs the same function as R_2 in figure 5-20. As in other electronic circuits, the circuit must be operated within limits determined by its components.

Mechanical Division

Mechanical division may be accomplished by using mechanical multipliers and by merely interchanging one input and the output.

Nonlinear Functions

Under this heading, instrumentation of various mathematical operations, such as raising a term to a power or extracting a root of a term, will be discussed. It shall also include the generation of trigonometric functions.

Most of these operations can be performed by mechanical, electromechanical, and electronic devices. However, one type of device may be more adaptable to a particular operation than another when considering the requirements of a computer. Nonlinear mathematical operations may also be performed by special applications of linear devices previously discussed. For example, a term may be raised to the second power by simply multiplying it by itself, using some type of linear multiplier.

POWER AND ROOTS

A variety of methods are used for solving problems involving powers and roots. The most common method utilizes electromechanical principles.

Powers

The solution of many problems requires use of devices capable of raising terms to a power. In most cases, the term is raised to the second power (squared).

There are several electronic circuits capable of performing this operation. Perhaps the simplest of the group is a modified use of the multiplying circuit previously discussed and shown in figure 5-11. By applying the input value to both grids 1 and 3, the output voltage will be proportional to the square of the input.

Another electronic circuit capable of squaring is called the squaring amplifier. It consists of a paraphase amplifier with its outputs driving push-pull triode amplifiers. Its output is also proportional to the square of the input, thus requiring a change in scale factor.

A common electromechanical method of raising a term to a power is by successive multiplication with potentiometer multipliers. Potentiometer type multipliers have been discussed previously and will not be reviewed in this section.

When the equation is $y = x^2$, ganged potentiometers may be used, provided x is the common shaft position of the potentiometers. This circuit is illustrated in figure 5-23.

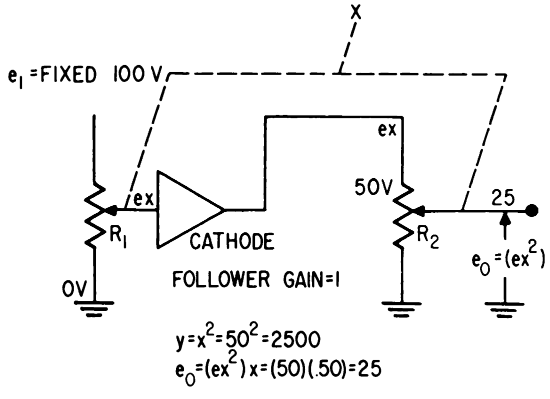


Figure 5-23.—Powers by successive multiplication.

The fixed voltage into R_1 is made proportional to the maximum value of x. The voltage (ex) at the variable tap of R_1 is at all times proportional to x. The voltage at the tap of R_1 is fed through an isolating circuit to R_2. The maximum voltage to R_2 is equal to ex. This voltage is again multiplied by x and the output voltage at the variable tap of R_2 is equal to x times ex, or ex^2. The variable may be raised to the third power, and so on by adding additional potentiometers.

The cam is a mechanical means of raisin a term to a power. However, its use is normally limited to squaring of a term. Figur 5-24 illustrates a basic square cam and tw types of followers used to transmit its outpu to other devices. The input positions the ca as indicated by the numbers around the outsid periphery of the cam. The follower then registers the output value in accordance with its position in the groove or on the curved surface. The output of a square cam will alway be of a positive value.

Roots

The root of a term may be extracted b either electromechanical or electronic devices

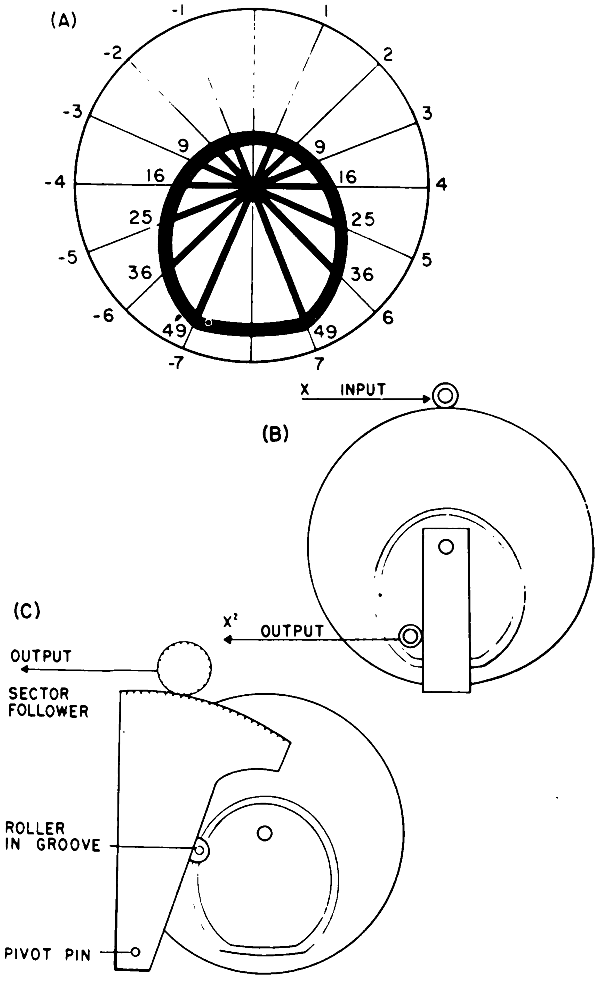


Figure 5-24.—Squaring cam.

In fact, any multiplying or integrating device capable of raising a term to a power and also capable of producing inverse functions can be used to produce roots. However, where required, the extracting of roots is normally accomplished by electromechanical devices. A typical device of this type is shown in figure 5-25.

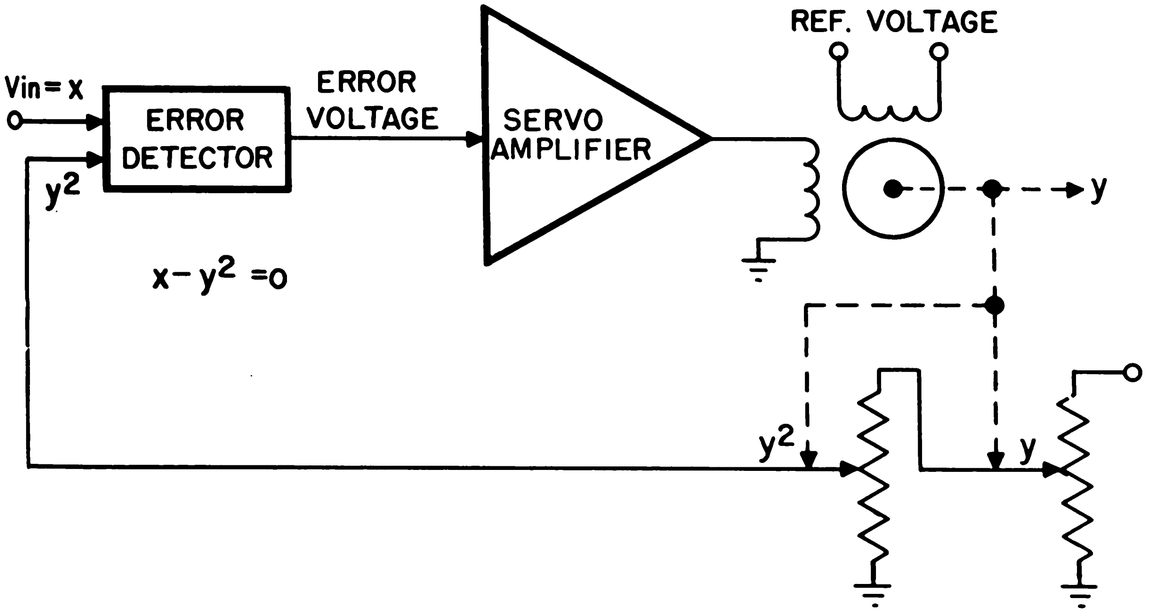


Figure 5-25.—Square root servomechanism.

An electromechanical device for extracting the root of a term or number is the servomechanism feedback loop which utilizes ganged potentiometers as shown in figure 5-25. The equation $y = \sqrt[n]{x}$ may be written as $x - y^n = 0$ by raising both sides to the nth power and transposing the y term. Now the term is in required form for servomechanism instrumentation.

Square root is solved by multiplying the output quantity y by itself and using this value as the feedback term. The output of the square root device is in the form of a shaft position, y.

TRIGONOMETRIC FUNCTIONS

Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. Electronic networks consisting of R and C are also sometimes used to perform some trigonometric functions, such as vector addition.

The trigonometric functions most often used in computers are sine and cosine values. However, the four remaining functions may be computed based on the sine and cosine.

NOTE: Anyone not familiar with the trigonometric identities should study chapter 5 of *Mathematics*, Vol. 2, NavPers 10070-A, and chapter 6 of *Advanced Mathematics*, NavPers 10071.

Electromechanical Devices

The inductive resolver is one of the most common electromechanical devices used to generate trigonometric functions. It is basically a right triangle solver, using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation corresponds to one of the angles of the right triangle that is to be solved.

The construction is very similar to a synchro, except that both the rotor and stator have two windings oriented 90 degrees from each other as shown in figure 5-26. Their primary use is to resolve a voltage into two components at right angles or to combine two component voltages into their vector sum.

When a rotor winding is parallel to one stator winding (fig. 5-27(A)), the device acts as a one-to-one transformer. As the rotor winding is rotated (fig. 5-27(B)), the voltage

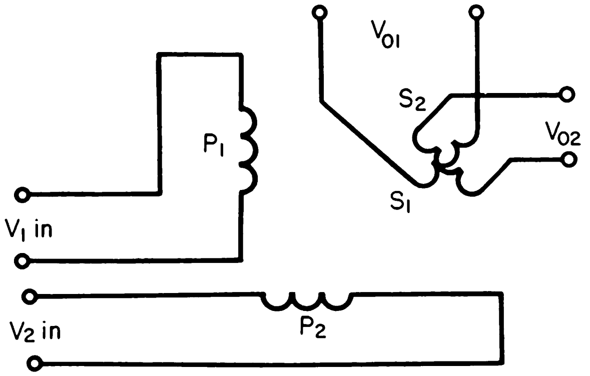


Figure 5-26.—Inductive resolver diagram.

induced depends on the sine of the angle of rotation times the applied voltage.

$$E_o = E_{in} \cdot \sin\theta$$

Figure 5-27 illustrates the action of the inductive resolver for three positions.

If the second rotor winding, as shown in figure 5-28, is at right angles to the first winding, its output will correspond to the rotation angle, since

$$\cos\theta = \sin(\theta + 90°)$$

Resolvers are low-impedance devices. Isolation or booster amplifiers are generally used as driving circuits if the inductive resolver input signal originates in a high-impedance source, such as a potentiometer. Isolation amplifiers have a low output impedance and can correct for any undesirable phase shift developed in the resolver. Since inductive resolvers operate only with a-c voltages, they cannot be used in d-c analog computers.

Many computer operations require that the computer be capable of transforming data from a polar to a rectangular coordinate system. If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates. The vector quantity, distance r and angle θ, may be resolved into horizontal and vertical distances, x and y respectively, with a 2-phase inductive resolver. By feeding a voltage representing the distance r into the one stator winding and rotating the rotor shaft correspondingly to θ, voltages representing x and y are produced at the rotor windings as shown in figure 5-29.

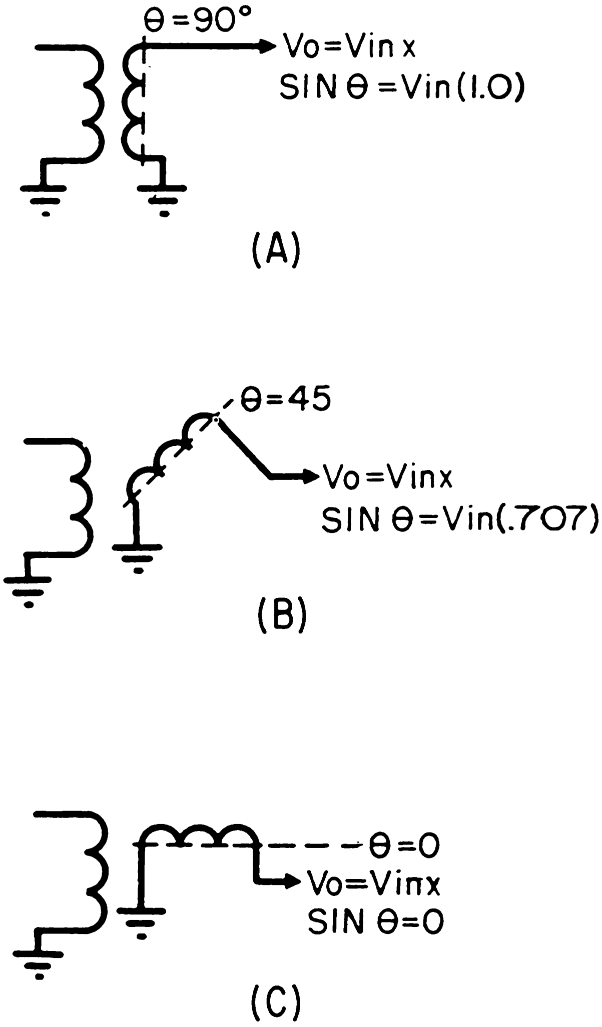


Figure 5-27.—Inductive resolver action.

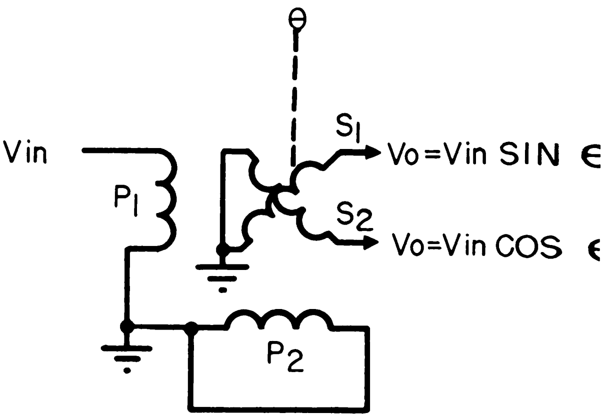


Figure 5-28.—Inductive resolver with two-phase winding.

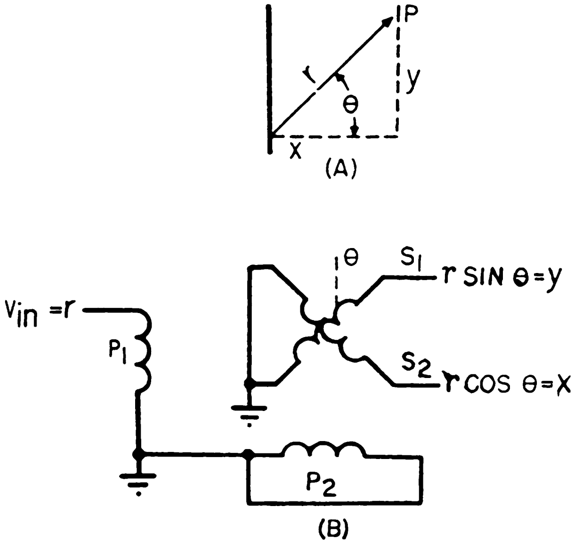


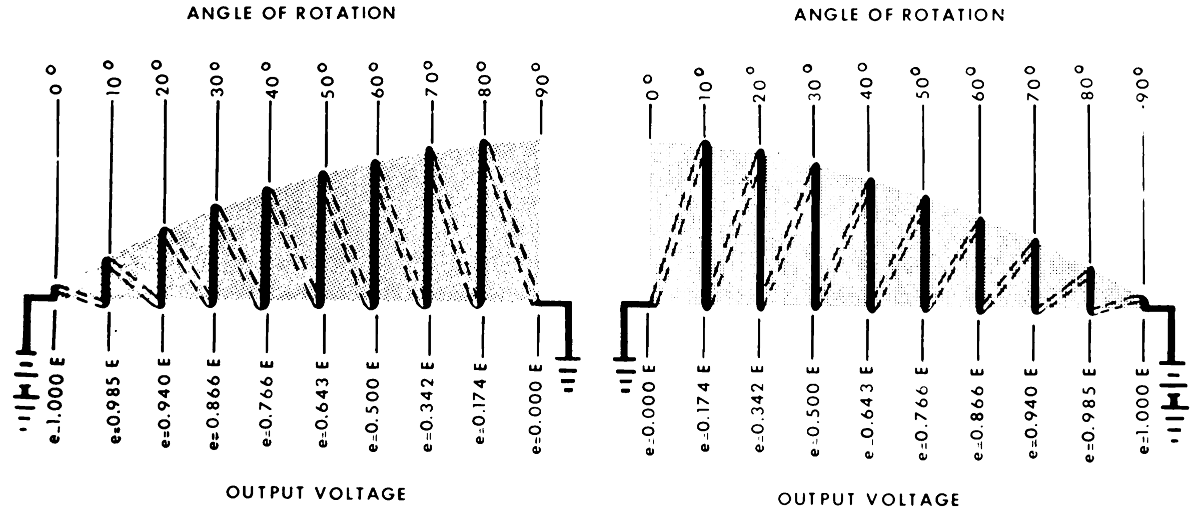
Figure 5-29.—Polar to rectangular transformation.

Sine and cosine potentiometers are specially designed devices for the selection of a voltage that is indicative of either the sine or cosine of an angle. Output voltages proportional to the product of the input voltage and either the sine or cosine of the angle through which the shaft is rotated can be obtained from specially designed potentiometers. Ordinarily, a potentiometer would have an even distribution of resistance across its entire length. It would then be classed as a linear control. If it had more resistance per unit length at one end than at the other, it would be classed as a tapered control. As an example, the travel through one-half the arc of a linear control results in one-half of the total resistance being between either end and the slider contact, while the travel through one-half the arc of a tapered control may result in one-tenth (or any fraction) of the total resistance being between one end and the slider.

There also exists a need for obtaining voltages proportional to other nonlinear functions, such as sine and cosine functions. This need has been satisfied by shaping a potentiometer card like a sine curve (as shown in fig. 5-30) and rotating the contact linearly.

The card must be accurately shaped to provide the correct ratio of voltage to degrees of rotation. For example, since the sine of 30 degrees is 0.5, it is evident that the output voltage should be one-half the applied voltage when the contact has completed 30 degrees rotation. Sometimes the shape of the card has to vary from the true sine curve in order to compensate for the thickness of the card and obtain the proper ratio.

A potentiometer can also be made to give cosine functions. The cosine card has exactly the same shape as the sine card except that the contact taps off a maximum value of applied voltage at 0 degrees and 0 volts at 90 degrees. The reason for this is that the cosine of 90 degrees is 0, and the cosine of 0 degrees is a maximum. With the type of cards shown in figure 5-30, it is possible to obtain voltages proportional to the sine or



COSINE CARD

SINE CARD

Figure 5-30.—Cosine and sine cards.

cosine of angles up to 90 degrees. Potentiometers have been constructed that will produce voltages proportional to the sine and cosine of any angle from 0 to 360 degrees.

The potentiometers just discussed use a linear movement of the contact and a nonlinear card. Another way to obtain a voltage proportional to these and other trigonometric functions is to use a linear card and a nonlinear movement of the contact.

Mechanical Devices

The tangent cam is a commonly used trigonometric device in mechanical computers. However, its operation must be limited to small angles due to the fact that the tangent of an angle ranges from zero to infinity. The tangent cam does not differ greatly from other cams except that the groove is cut differently and the output is a function of the input angle and is the tangent of that angle. Figure 5-31 illustrates a tangent cam.

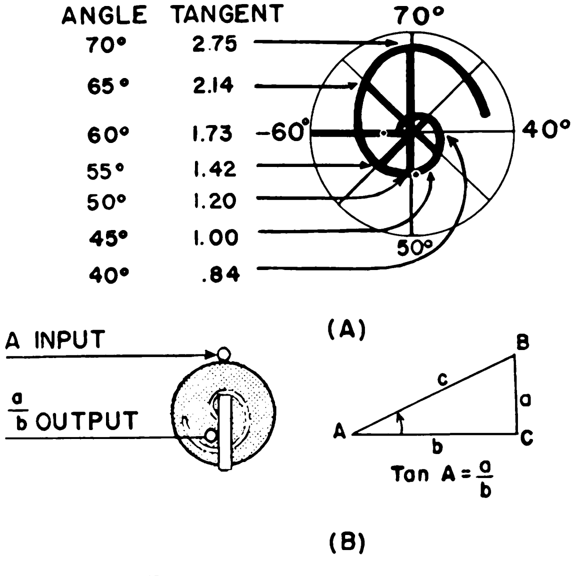


Figure 5-31.—Tangent cam.

Component solvers and vector solvers are devices that are also used in mechanical computers. The name of each indicates its respective method of operation and, as in inductive resolvers, one is nearly the reverse of the other. The component solver takes a vector of some magnitude and angular position and resolves it into its two rectangular components. The vector solver performs just the opposite operation by taking the two rectangular components and solving for a vector at a angular position.

There are several types of component an vector solvers. However, this discussion wil be limited to the screw type component solver The device consists of a vector gear, tw racks, two output gears, two input gears, an a screw and pin assembly. The speed inpu gear drives a gear train which causes th screw to turn. As the screw turns, it drive an assembly carrying the pin, thus changin the length of the vector which is proportiona to the input component, such as r (slant range (See fig. 5-32.)

In this type component solver the pin ca travel nearly the full width of the vector gea From the pin's zero or center position it ca be moved in either of two directions whic corresponds to positive or negative directions

The vector input gear drives the vecto gear in the desired angular direction indicat ing target position, θ. The pin positions th racks as it moves along the slot, thus resolv ing the vector into its components. Therefor it solves for the desired quantities as show in figure 5-33.

LOGARITHMS

A study of logarithmic processes in *Math ematics*, Vol. 2, NavPers 10070-A, will indi cate the ease of raising a term to a power o extracting a root of a term with the use o logarithms. However, in this section device for obtaining the logarithm of a term will b discussed.

Diodes and contact rectifiers under som conditions have nearly exponential variatio of current with voltage, or logarithmic varia tion of voltage with current. However, th operating limits of a single diode are su passed by the requirements of most aircra computers. This limitation necessitates th use of circuits such as are shown in figure 5- to produce logarithmic functions.

The purpose of this circuit is to produ an output voltage that is proportional to th logarithm of the input current. Referring figure 5-34, it should be noted that R_2, R and R_6 form a voltage divider network. Th cathode of each rectifier is connected throu a resistor to some point on the voltage divide This effectively acts as bias, causing ea rectifier to be cut off until its plate reaches potential higher than its cathode.

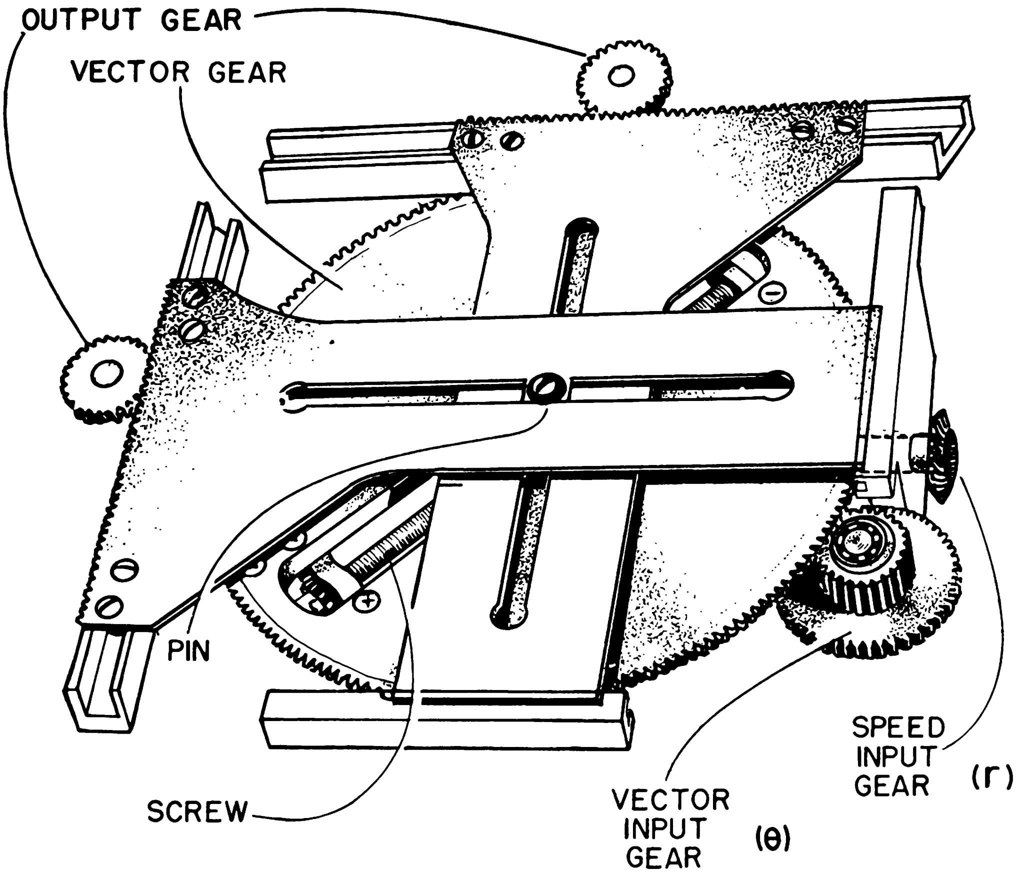


Figure 5-32.—Component solver.

As the input current is applied, current flow will be up through R_1 producing an output voltage proportional to the current ($E = IR$). As the current, hence the voltage drop across R_1, becomes great enough, the top of R_1 will become positive enough to bring CR_1 into conduction. As soon as CR_1 conducts, it effectively places R_3 in parallel with R_1, lowering the total resistance and producing less voltage drop for a given increase in input current. This accounts for the bend in the curve at point a. The circuit response curve illustrates how the slope is successively reduced as additional rectifiers come into conduction. It should also be noted that an increased number of rectifiers could result in a more perfect curve. However, the circuit shown provides an output well within the tolerances required for most airborne computers.

There are several means available of obtaining the antilogarithm of a quantity. This may be done either by employing an exponential characteristic directly or by the use of a feedback loop. Implicit methods may also be used such as taking the derivative of the term eliminating the logarithm in the equation.

Calculus

Calculus is a branch of mathematics that deals with the rate of change of a function and with the inverse process which is the determination of a function from its rate of change. The process of determining the rate of change of one variable with respect to another is called differentiation or differential calculus. The process of determining the sum of many minute quantities is referred to as integration or integral calculus.

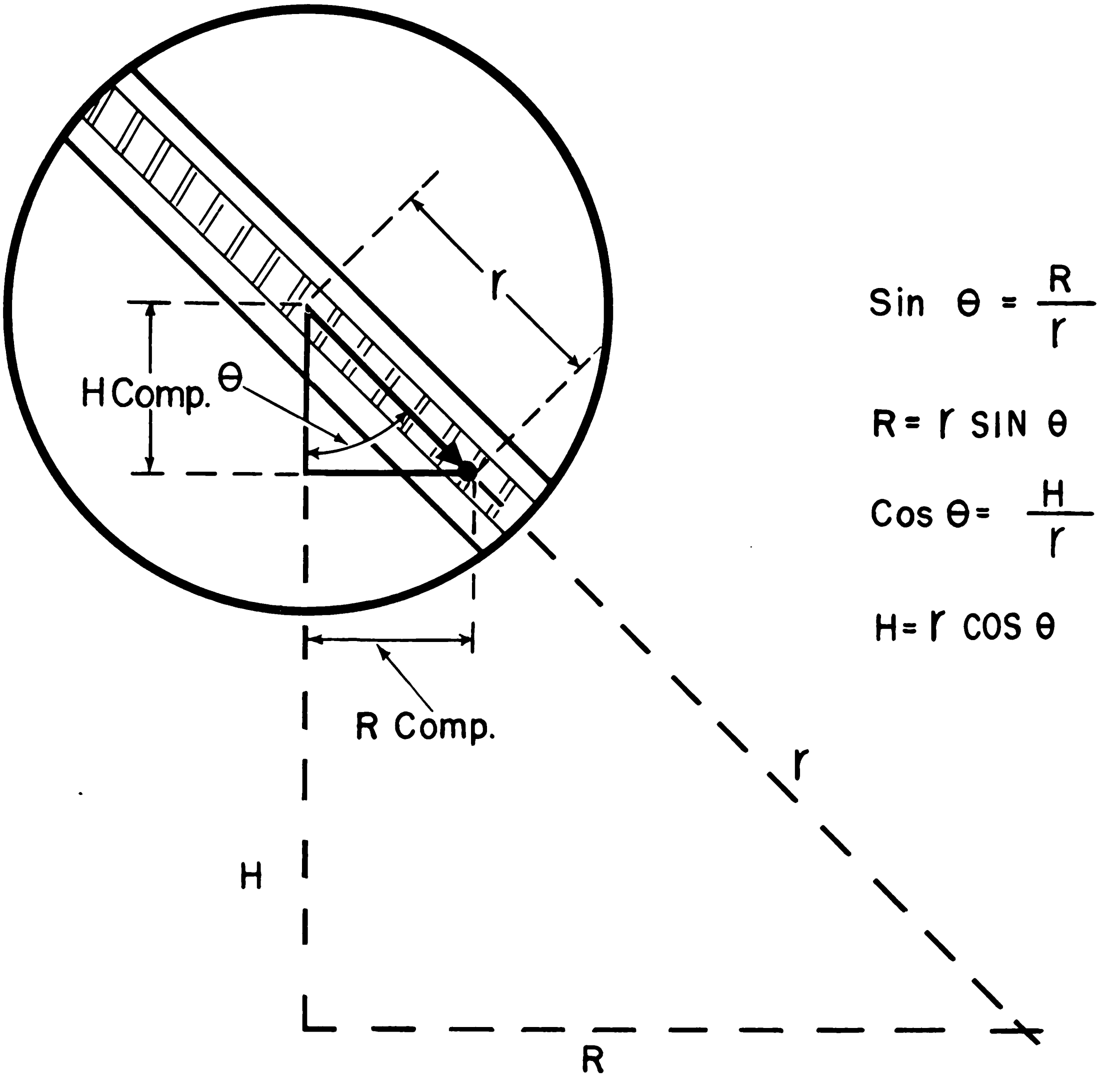


Figure 5-33.—Problem solution by component solver.

DIFFERENTIATION

Before studying the actual process of differentiation, a discussion of the terminology to be used will be given. Consider the equation $x = f(y)$. It should be read as: x equals a function of y. If the derivative of x is taken with respect to y, then it would be written as:

$$\frac{dx}{dy} = \frac{d\,[f\,(y)]}{dy}$$

which, in notation form, is

$$\frac{dx}{dy} = f'\,(y)$$

$$dx = f'\,(y)\,dy$$

By now it should be obvious that the prim indicates the first derivative of the functio

Although y represents any variable, interes in the derivative is usually with respect t time. The derivative of a quantity with respe to time can be thought of as the time rate change of that quantity. For motion along straight line, for example, the derivative the distance traversed with respect to time i the velocity or the time rate of change of distance. Similarly, the derivative of a voltag with respect to time is the time rate of chang of that voltage. Figure 5-35 shows a graphic representation of the derivative of a voltag If a voltage E_{in} is changing at a constant ra as shown in (A) of figure 5-35, then t

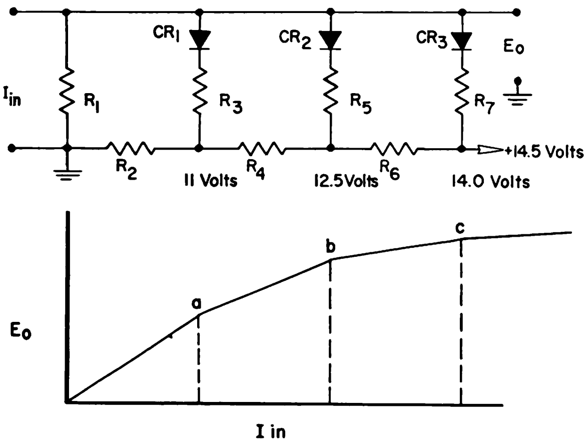


Figure 5-34.—Typical logarithmic shaping network.

derivative E_o of that voltage has a constant value as shown in (B) of figure 5-35. A common symbol for the time derivative of a quantity is x.

Electronic Differentiation

The rate at which an input voltage is changing can be obtained from a simple series-connected resistor and capacitor circuit as shown in (A) of figure 5-36.

Notice that the output voltage of this circuit appears across the resistor. With the proper values of R and C to provide a short RC time constant and with a square-wave input voltage E_{in}, the output voltage E_o will be that shown in (B) of figure 5-36. When the rate of change of E_{in} is greatest, the value of E_o is greatest; and when the rate of change of E_{in} is zero, the output E_o tends toward zero. The derivative of a triangular wave or a sawtooth wave is shown in (C) of figure 5-36. These facts illustrate that the output voltage is approximately equal to the rate of change (derivative) of the input voltage.

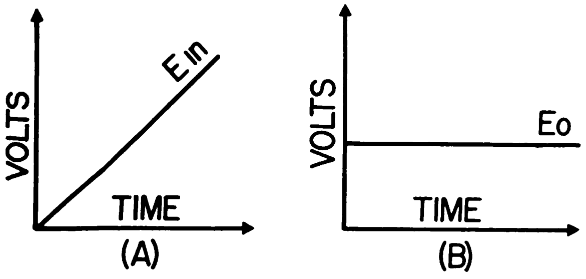


Figure 5-35.—Graphic representation of the derivative of a voltage.

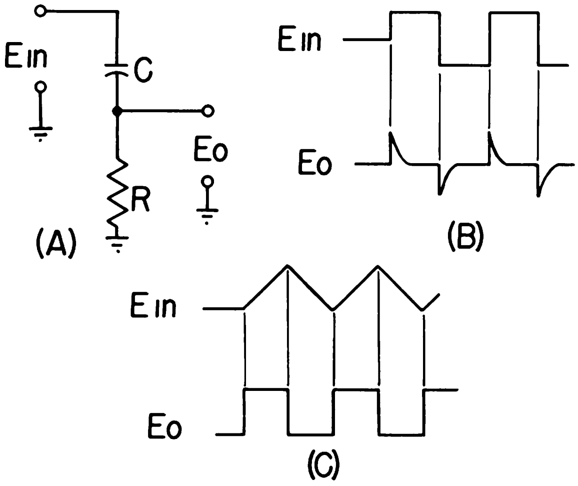


Figure 5-36.—Simple differentiating circuit.

The primary disadvantage of the simple differentiating circuit is the time required for the output voltage to become equal to the derivative of the input voltage. Shortening the RC time constant to decrease this time decreases the amplitude of the output voltage.

A feedback amplifier differentiator is shown in figure 5-37. This type of differentiator is superior to the simple differentiator circuit because its output voltage approximates the derivative of the input voltage in a much shorter time and with greater accuracy.

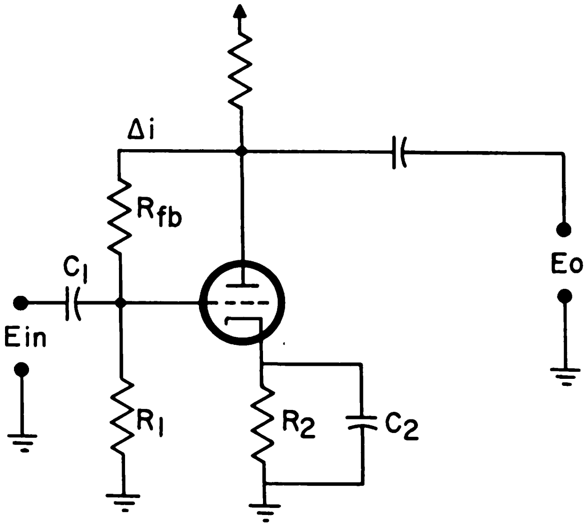


Figure 5-37.—Differentiating circuit using a feedback amplifier.

In the following discussion involving the application of a feedback amplifier, it is presupposed that you have a thorough understanding of the theory of negative feedback amplifiers. If you do not possess this understanding refer to *Basic Electronics*, NavPers 10087.

Before discussing the operation of the differentiator amplifier circuit, the following conditions are established:

1. The amplifier must be biased so as to operate near the center of its linear range and not draw any grid current when operating within its specified limits.
2. The grid voltage will be near ground potential and will change only a very small amount when the input signal varies. This occurs because the feedback voltage tends to prevent any change in grid voltage.
3. Since the grid voltage will remain almost constant, any change in plate voltage due to an input signal will appear almost entirely across the feedback resistor causing a corresponding change in current through it. Therefore, the output voltage E_o is given by the formula

$$E_o = -\Delta i \, R_{fb}$$

Where

E_o is the change in plate voltage (a-c component) resulting from an input signal applied to the grid. Δi is the change in current flowing through the feedback resistor.

R_{fb} is the feedback resistor.

The formula will now be restated in more simple terms, keeping in mind that a differentiator can only produce an output when there is a change in the input voltage. The amplitude of the output voltage (a.c.) is equal to the change in feedback current (a-c component) multiplied by the resistance of the feedback resistor. The negative sign is to correct for the polarity inversion of the amplifier.

Consider the action of the circuit with a constantly changing voltage applied. (See fig. 5-37.) For simplicity of explanation, consider a back-to-back sawtooth that is starting downward from its apex. As the negative-going signal starts downward, electrons from the grid side of C_1 will start to flow through R_{fb} (electrons are attracted to the higher potential of the plate), causing the grid voltage to drop. This action reduces plate current causing a rise in plate voltage. However, a portion of the plate voltage increase is fed back to the grid causing it to rise in potential. (NOTE: Since the feedback voltage is only a small portion of the plate signal, the grid cannot come back to its initial voltage.) The grid and plate will reach a state of equilibrium instantaneously and remain as long as the current through R_{fb} is constant. With the linear input voltage, the discharge current of C_1 will remain constant through R_{fb} until the input reverses its direction.

Since the plate is the source of the output, observe its action closely. Remember that the output is only the a-c component of the plate voltage. When the input signal started downward, the plate voltage shot up and leveled off instantaneously and remained at this level until the input signal reversed its direction. This produced a square-wave output that is opposite in polarity to the input. The other half cycle will produce a similar output. Therefore, the output is a voltage waveform indicative of the rate of change of the input voltage. This input voltage may represent an input variable such as range, and the output voltage may represent range rate or velocity.

Electromechanical Differentiation

When the derivative of a voltage is desired, a generator driven by a servomechanism may be used. In this case the servo transforms the voltage to be differentiated into a corresponding shaft position. A generator which is driven by the servo shaft produces an output voltage proportional to the speed of the motor. The generator voltage is a derivative of the rotor displacement with respect to time or a measure of the rate of rotor rotation. (See fig. 5-38.)

The derivative range is limited by the response of the servomechanism. A system having moving parts with appreciable inertia cannot respond to a voltage step function, where the slope is infinite.

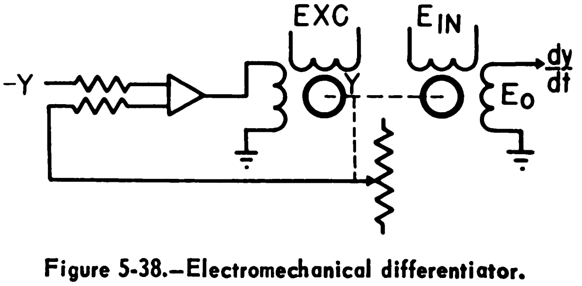


Figure 5-38.—Electromechanical differentiator.

Mechanical Differentiation

The derivative of a shaft rotation can be obtained by a mechanical ball-disk-roller differentiator such as the one illustrated in figures 5-39 and 5-44.

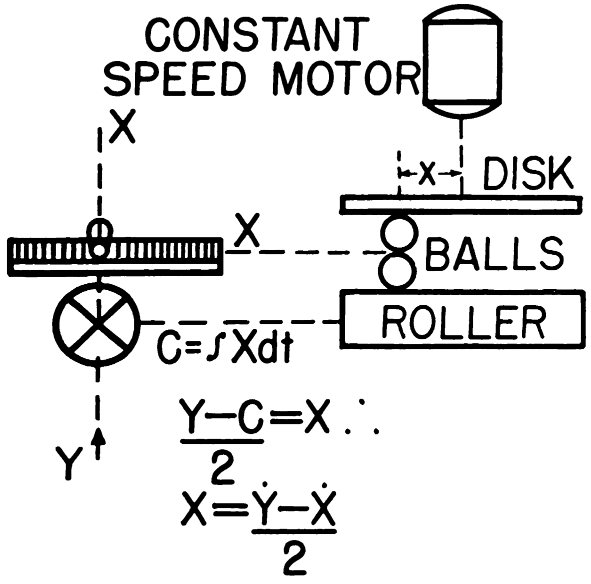


Figure 5-39.—Ball-disk-roller differentiator.

The differentiator is essentially an integrator which can be used with feedback to obtain the derivative of one quantity with respect to another. (NOTE: This is an implicit method of problem solving.) The device differentiates the quantity y with respect to time t and produces an output proportional to this rate.

Basically, the device consists of a flat rotating disk, driven by a motor at a constant rate; a ball and carriage assembly; and a roller. (NOTE: A detailed discussion of the operation of the basic device is covered later in this chapter under the heading "Mechanical Integrator.") The inputs are y, a shaft rotation, and t, which is the constant speed of disk rotation. Referring to figure 5-39, note that the input y is fed to a mechanical differential. The differential also is coupled to the roller. The output of the differential is a shaft rotation that is equal to one-half the difference between the two input rates. For example, if the y input is 50 r.p.m. and the roller is 45 r.p.m., the output would be at the rate of 2.5 r.p.m.

As in any system employing corrective feedback, the output of the differential must in some way cause the roller speed to be increased so it will be the same as the y input shaft. This is accomplished by having the differential output shaft drive a gear rack which is mechanically coupled to the ball and carriage assembly. Since the roller's rate of rotation should be increased to equal the y input, the gear rack moves the ball and carriage assembly in an outward direction sufficiently to increase the roller's speed to equal the speed of the input shaft.

The output is also taken from the gear by use of a pinion gear to drive an output shaft. The output shaft's position will be indicative of the rate of rotation of the y input.

INTEGRATION

As pointed out previously, integration is the process of summing up an infinite number of minute quantities. However, in the solution of certain problems, integration is the summing of certain quantities in respect to time. For example, taking the integral of velocity between certain limits of time will give the distance traveled.

The process of integration is analogous to determining the area under a curve. In the case of a step function input, it may be considered as a rectangle having one side variable with time. In figure 5-40 (A), the solid curve Y_1 shows the velocity at any time—in this case a constant velocity.

The distance traveled is equal to the velocity multiplied by the time; and with proper scale values, this distance is given by the numerical area under this (rectangular) curve; that is, area=height (or velocity) multiplied by length (or time). On the distance-time

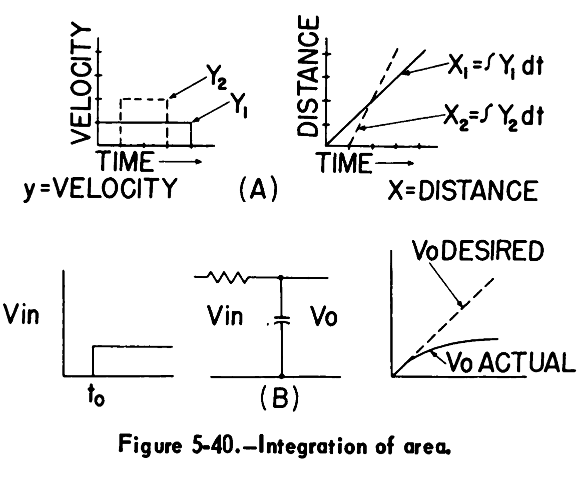


Figure 5-40.—Integration of area.

diagram, the sloping line X_1 shows the total distance traveled at any instant of time; and the larger the step input the steeper the slope of the line in the distance-time diagram. Finally, lines Y_2 and X_2 represent another case.

The distance traveled, x, must continue to increase as long as there is a positive value of velocity, y. When x is represented by a voltage, there are limitations on its maximum value due to circuitry to be used.

The integral of a d-c voltage is a voltage with a constant slope as shown in figure 5-41. There is normally no need of integrating d-c voltages, but this effect is identical to the voltage wave for step inputs.

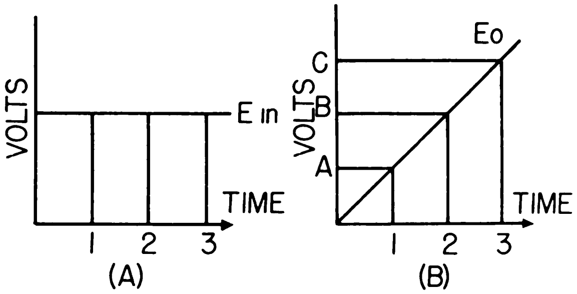


Figure 5-41.—Graphical representation of integration of a voltage.

A simple integrator is shown in (A) of figure 5-42. Here a square-wave voltage is applied to the input, and the output voltage appears across the capacitor. During the positive portions of the input voltage, the output voltage is the sum of all the positive quantities, which results in an increasing voltage. During the negative portions of the input voltage, the output voltage is the sum of all of the negative quantities in the input, which results in a decreasing voltage. Study the waveforms in (B) of figure 5-42 and compare them with the output of the simple differentiator circuit of figure 5-36.

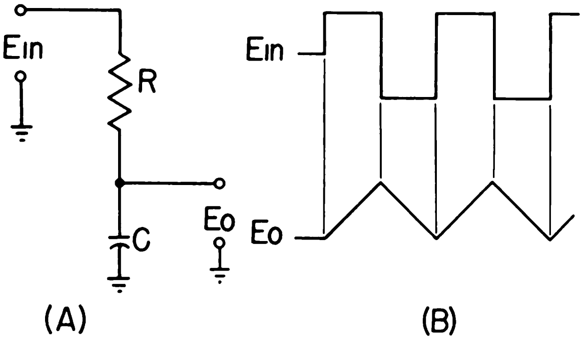


Figure 5-42.—Simple integrating circuit.

An integrator circuit utilizing a feedback amplifier is shown in figure 5-43. This circuit is very similar to the differentiator amplifier circuit discussed previously. However, it should be noted that the negative feedback is coupled from plate to grid with a large coupling capacitor. This capacitor, along with its associated resistors, perform the integration. The amplifier functions only to improve its response and linearity. The input circuit also utilizes an isolation resistor R_1 to allow the grid to be maintained at an almost constant potential when an input signal is applied.

The output is based on the rate of charge, or discharge, of the feedback capacitor. The amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage and the capacitor charging current is a direct function of the input signal voltage.

Mechanical Integrator

This is a mechanical device whose function is the same as the electronic integrator previously discussed. An example of the mechanical integrator is found in the ground position computer used in navigation. This computer gives a continuous visual indication of ground position in longitude and latitude at all times

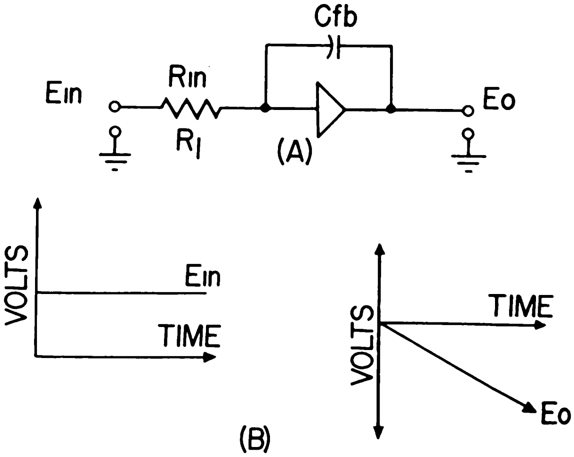


Figure 5-43.—A common integrating circuit.

during flight. This is done by computing and indicating changes in longitude and latitude as they occur. At the start of the flight the position of the home field is set in manually. The operation of the longitude computing channel is practically the same as the one for latitude, so only one will be discussed—the channel for longitude.

If the longitude rate (minutes of longitude traversed per unit of time) were constant, a simple rate-times-time multiplier could be used to compute longitude position at all times. However, longitude rate generally is not constant. For example, if the aircraft is flown due north, directly along a line of longitude, the longitude indication would not change. Its longitude rate would be zero. When flying due east or west, its longitude rate would be maximum. The ball-disk-roller integrator (fig. 5-44) is used in the ground position indicating navigational computer.

Study the diagram and note the following:

1. The disk is mounted on a gear and is turned directly by an input gear that is meshed with it.
2. The two steel balls, one on top of the other, are held in position by a carriage which runs along a pair of guide rails (not shown) across the face of the disk.
3. The balls turn the roller, which has an output gear at one end.
4. The balls can be positioned by the carriage anywhere along a straight line from one edge of the disk across the center to the other edge.
5. The circumference of the circle passing under the balls is greater when the balls are near the edge of the disk than when they are near the center.
6. The balls rotate faster when they are at the edge of the disk, and slower near the center.
7. When on one side of the center, the balls turn in one direction, and when on the other side of the center, they turn in the opposite direction.
8. The pressure needed to hold the balls against one another, and against the disk and roller comes from a calibrated spring or springs.

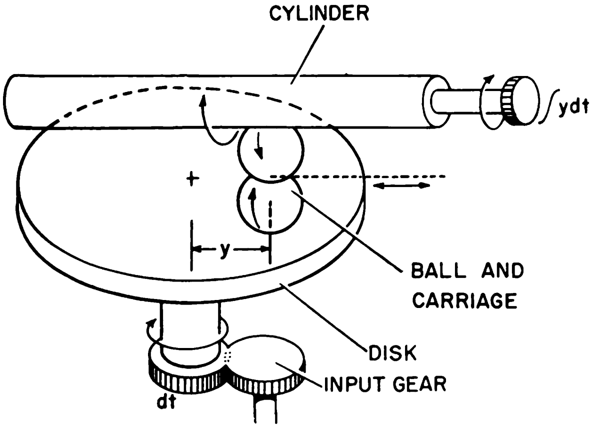


Figure 5-44.—Ball-disk-roller type mechanical integrator.

At the beginning of the flight, the known longitude of the starting position of the mission (usually home field longitude) is set with a manual knob into the longitude indicator. At that point, the disk is set in motion at a constant speed (r.p.m.). The disk's fixed r.p.m. represents the steady passage of time. Longitude rate for each instant is fed from the longitude rate computing section into the carriage input gear, which positions the balls on the disk. If longitude rate is large in one direction (flying due east, for instance), the carriage positions the balls near one edge, causing maximum roller output r.p.m. in one direction. If longitude rate is zero (flying due north or south, for instance), the balls are positioned at the disk's center. They are not rotated, and therefore, the output roller r.p.m. is also zero. Maximum longitude rate in the opposite (due west) direction would position the balls at the opposite disk edge, with maximum r.p.m. in the opposite direction. The roller output drives the longitude indicator, giving a continuous longitude reading which is actually the integration of all instantaneous longitude rates.

Grouped Operations

Thus far in this chapter computing devices for performing various mathematical operations have been discussed individually. At this point several of the instruments or devices will be grouped together for the solution of a problem. It is not intended that such grouping will comprise a workable computer, but rather to show that the grouping of devices allows the solution of more complex equations.

PROBLEMS ENCOUNTERED IN GROUPED OPERATIONS

When various devices are selected to carry out a grouped operation, certain problems are almost certain to develop. Such problems are present even in the grouping of the simplest devices. Here again this information is presented not to help you design a computer, but to aid you in understanding the more complex computers.

Change of Representation

With the connecting of two or more computing devices, the use of two or more methods of representation are frequently required. The output of the first device may not have the same representation as required by the input of the second device. An example might be the multiplication of two voltages by a potentiometer type multiplier. To successfully multiply, one of the voltages would have to be represented by a shaft rotation.

Scale Factor

Another problem that must be considered when grouping two or more devices is that of scale factor. As pointed out previously in this chapter, a change of scale factor takes place any time the device produces a proportional output. This includes devices such as adding, multiplying, dividing, etc.

Impedance Matching

When the output of one electronic circuit is fed to another, the input impedance of the second circuit or stage may affect the operation of the first. Therefore, it is important that the input impedance of the second circuit be matched to the output impedance of the driving stage. A mismatch may result in an error in the computer, making the complete computation inaccurate. Two devices often used between two computing circuits are the cathode follower and impedance matching transformers. Impedance matching in the use of electrical components, such as resolvers and control transformers, must also be considered.

Relative Speed of Computation

The speed of response of a device is important in grouped operation. Some devices have a shorter response time than others. For example, a device with a minimum speed of computation time, when required to function longer than the minimum time, may lose a considerable percentage of its accuracy. The overall accuracy of a group of devices could be reduced below the desired tolerance due to one device requiring a longer time to function than the rest of the group. The speed of response is an important factor in regard to the stability of computers utilizing feedback.

EQUATION SOLVER

In the solution of some problems, it is necessary to find the hypotenuse of a right triangle when the length of the two sides are given. For example, bombing computers normally utilize ground range or horizontal range because ground range rates are more constant than slant range rates. However, to minimize the possibility of error, computed ground range is converted into slant range for comparison with observed radar range. This requires a constant solution from the following equation:

$$r = \sqrt{H^2 + R^2}$$

Where r = slant range

H = altitude

R = ground range.

A block diagram of a squaring-type triangle solver is shown in figure 5-45. The quantities H and R are squared and summed. The summed quantity $(R^2 + H^2)$ is fed to a device that extracts the square root, giving an output equa to r.

A simplified circuit capable of performing the above operation is illustrated in figure 5-46. The quantities H, R, and r are represented by their respective shaft positions. Ganged potentiometers are used for squaring each quantity. A voltage proportional to $H^2 + R^2$ appears across R_4, and is fed to a feedback amplifier. Here the signal is amplified and the scale factor is corrected prior t being fed to the difference amplifier.

Potentiometers R_{15} and R_{16} are also squaring potentiometers with the output being

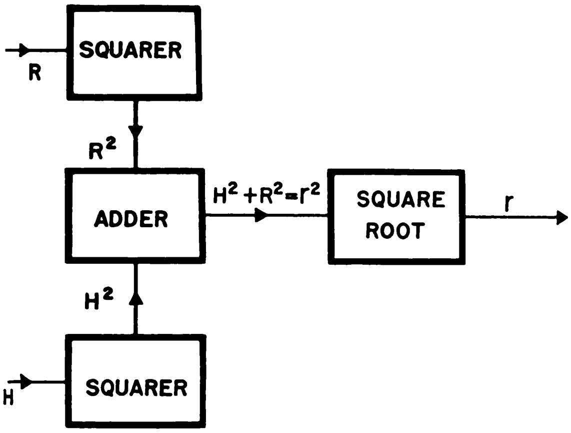


Figure 5-45.—Block diagram of right triangle solver.

voltage proportional to r^2. This signal is also amplified and fed to the difference amplifier. If the voltage r^2 is equal to the voltage $H^2 + R^2$, the output from the difference amplifier is zero and the position of the r shaft is indicative of $\sqrt{H^2 + R^2}$. However, if there is a difference in the two inputs, the output signal fed to the servo amplifier will cause the servomotor to rotate in a direction to reduce the difference voltage, thus correcting the output r.

It should be remembered that this example is only one of many possible ways of solving a right triangle. It is included only to show that the devices discussed earlier in this chapter may be grouped for the solution of more complex equations.

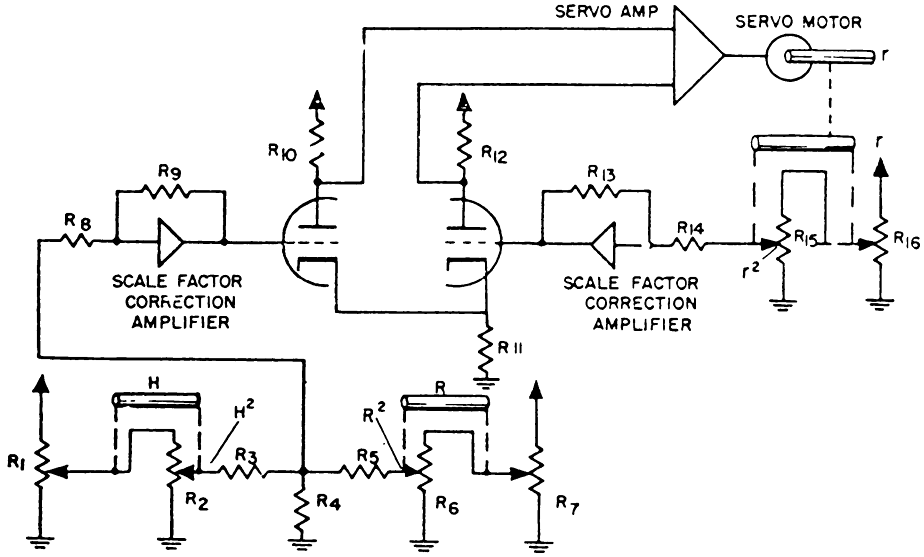


Figure 5-46.—Schematic diagram of a right triangle solver.

QUIZ

1. The two main classifications of computers are
   - a. digital and mechanical
   - b. digital and analog
   - c. analog and mechanical
   - d. analog and electromechanical

2. In the binary system, eight pieces of information may be represented by the use of______digits.
   - a. 6
   - b. 8
   - c. 5
   - d. 3

3. In analog type computers, summation may be accomplished with
   a. mechanical devices only
   b. mechanical, electromechanical, or electrical devices
   c. electromechanical devices only
   d. electronic devices only

4. While performing addition using the series circuit shown in figure 5-1,
   a. only one of the input voltages (E_1 and E_2) can be grounded
   b. both of the input voltages (E_1 and E_2) can be grounded
   c. only a-c voltages can be used
   d. only d-c voltages can be used

5. The device most commonly used for electromechanical multiplication is the
   a. multiplier
   b. potentiometer
   c. differential
   d. integrator

6. The trigonometric functions most often used in aviation computing equipment are the
   a. secant and cosecant
   b. cosecant and cotangent
   c. sine and cosine
   d. tangent and cotangent

7. The output from a negative feedback amplifier differentiating circuit, as illustrated in figure 5-37, with a back-to-back sawtooth input is a
   a. peaked wave
   b. square wave
   c. sine wave
   d. sawtooth wave

8. The three main types of aviation computers are
   a. mechanical, analog, and electromechanical
   b. mechanical, electromechanical, and digital
   c. electronic, mechanical, and analog
   d. mechanical, electronic, and electromechanical

9. Arithmetical operations in a digital computer are accomplished in the
   a. input unit
   b. output unit
   c. control unit
   d. logical unit

10. The implicit form of the explicit term $C = \sqrt{a}$ is
    a. $C^2 = a$
    b. $C^2 = a^2$
    c. $a = \frac{C}{a}$
    d. $a^2 = C$

11. When subtracting two a-c voltages by the series circuit method,
    a. both input voltages should be grounded
    b. the inputs should be 180 degrees out of phase
    c. the phase relation has no effect on the results
    d. it is necessary to use two transformers

12. Autotransformer multiplication is possible with
    a. d-c voltage only
    b. a-c or d-c voltages
    c. a-c voltage only
    d. a-c and d-c voltages

13. The inductive resolver has two rotor windings oriented ______ degrees from each other
    a. 45
    b. 60
    c. 90
    d. 120

14. Mechanical differentiation can be obtained by a mechanical
    a. coupling
    b. integrator
    c. worm gear
    d. bevel gear

15. In the majority of electronic digital computers, the coding system used is the
    a. powers of ten system
    b. binary system
    c. decimal system
    d. metric system

16. The backbone or heart of a digital computer is the
    a. input unit
    b. logical unit
    c. memory unit
    d. control unit

17. Any operation in an analog computer tha does not change the mathematical quantity represented is called a/an
    a. resultant operation
    b. identity operation
    c. summation operation
    d. integration operation

18. In a parallel resistive summation networ the output voltage is
    a. the actual sum of the input voltage
    b. proportional to the sum of the inp voltages
    c. twice the sum of the input voltage
    d. always an a-c voltage

19. When using a rheostat for electromechanical division, the input voltage is applied to
    a. one end of the rheostat
    b. the movable arm of the rheostat
    c. both ends of the rheostat
    d. one end and the movable arm of the rheostat

20. In the mechanical component solver illustrated in figure 5-32 the pin assembly
    a. can move in either of two directions
    b. can move in a positive direction only
    c. is not free to move
    d. can move in a negative direction only

21. The output voltage of an electronic RC integrator appears across
    a. the capacitor
    b. the resistor
    c. the resistor and capacitor
    d. neither the resistor nor capacitor

22. The binary system is based on the number _____ raised to some power.
    a. 2
    b. 4
    c. 10
    d. 20

23. The process of summation in an analog computer can be accomplished with
    a. electrical devices only
    b. mechanical devices only
    c. electrical or mechanical devices
    d. motions only

24. A change of scale is accomplished by multiplication of the data by a
    a. variable quantity
    b. nonlinear quantity
    c. fixed quantity
    d. variable proportional quantity

25. The input voltages to an electron tube difference amplifier
    a. are always positive voltages
    b. are always negative voltages
    c. are always equal in amplitude
    d. need not be from an isolated source

26. In electronic division a vacuum tube is used in place of the ______ in a rheostat divider network.
    a. dividend
    b. quotient
    c. fixed resistor
    d. variable resistor

27. The output voltages from an electronic RC differentiation network appear across
    a. the capacitor
    b. the resistor and capacitor
    c. neither the resistor nor capacitor
    d. the resistor

28. In an integrator circuit utilizing a feedback amplifier as illustrated in figure 5-43, the output is based on the
    a. size of R_{in}
    b. voltage drop across R_{in}
    c. size of C_{fb}
    d. rate of charge, or discharge of C_{fb}

29. The number representation 1,011 in the binary system is equal to_____ in the decimal system.
    a. 21
    b. 16
    c. 15
    d. 11

30. In an analog computer, the mathematical operation of raising a term to a power is expressed algebraically as
    a. $Y = X^n$
    b. $Y = X$
    c. $Y = \sqrt{X}$
    d. $Y = \frac{1}{X^n}$

31. A linear function in mathematics is one that can be shown by a/an ______ line on a graph.
    a. curved
    b. straight
    c. exponential
    d. logarithmic

32. The device most commonly used for mechanical summation is the
    a. multiplier
    b. integrator
    c. bevel gear
    d. differential

33. Mechanical division may be accomplished by using mechanical
    a. differentials
    b. multipliers
    c. hangers
    d. collars

34. In a mechanical ball-disk-roller type integrator
    a. the balls always rotate in the same direction
    b. the balls rotate faster when they are at the edge of the disk
    c. the balls rotate faster towards the center of the disk
    d. only one-half of the disk is ever used

35. Linear functions include those functions that involve
    a. square roots, multiplication, and division
    b. squares, summation, and division
    c. summation, multiplication, and division
    d. division, multiplication, and trigonometric functions

36. The device most commonly used to change a mechanical input shaft rotation to an electrical signal (voltage) output is the
    a. synchro transmitter
    b. synchro receiver
    c. transformer
    d. integrator

37. A term may be raised to a power mechanically by using a
    a. cam
    b. differential
    c. bevel gear
    d. hanger

CHAPTER 6

AIRCRAFT ELECTRIC POWER SYSTEMS

In order for you, the technician, to properly operate and maintain the electrical and electronic equipment in an aircraft it is necessary that you have an understanding of the electrical power system of the aircraft. You must understand the system so that you will be able to recognize and meet the electrical emergencies that may occur during flight. If you fulfill your important duties as a member of your squadron and aircrew, you must have a fundamental knowledge of the means by which aircraft electrical power is produced, regulated, controlled, and distributed. With this basic understanding you will be able to recognize and to analyze any emergencies that require immediate action, and either to correct the cause or replace the defective part. In so doing, you can make maximum use of the equipment for which you are responsible.

Many naval aircraft contain two electrical systems—a direct-current system which supplies current at 24 to 28 volts, and an alternating-current system which supplies both 115 volts, single-phase power and three-phase power at either 115 or 208 volts. External power receptacles are located on the aircraft and provide a means of attaching external sources of power to the aircraft for engine starting and ground operation of the electrical and electronic equipment. In addition to this, many of the larger aircraft are also equipped with an auxiliary power unit (APU) to provide power in emergencies, while the aircraft is on the ground, or during water operations. The auxiliary power unit consists of an independently operated gasoline engine which drives a generator; the generator supplies power to the electrical system.

These sources of power are connected through switches and other control units to a primary bus system. The primary bus usually consists of a bar of good conducting material, such as copper, aluminum, or brass. In some installations the bus is in the form of a bolt connection. Connected directly to the primary bus are the fuses and circuit breakers which supply system voltage to various electrical circuits throughout the aircraft.

The connections are either enclosed in junction boxes, or otherwise well insulated from the airframe. In small aircraft, there is usually a single distribution point which is referred to as the primary bus. In larger aircraft, the primary bus may consist of a number of individual distribution points located at various stations within the aircraft.

An essential, or emergency, bus system is provided to connect power to essential circuits, such as certain flight instruments, in the event of power failure of the primary bus. These are circuits that must have power if controlled flight is to be maintained.

A few circuits are not connected through either the essential or the primary bus, but are connected directly to the battery and have power available to them at all times. These consist of submersion actuator circuits, boarding lights, and electronic destructors that may be installed. The schematic diagrams in the *Handbook of Maintenance Instructions* indicate which bus supplies power to any particular circuit.

Generating Systems

Two types of generators are used on naval aircraft; one type produces direct current and the other produces alternating current. The generators are driven by the aircraft's engine. On most piston-type engines the accessory section has provisions for driving two generators. If it is a single-engine aircraft one of the generators could be a direct-current generator and the other an alternating-current generator. On a multiengine aircraft one engine might drive two direct-current generators and another engine might drive one direct-current generator and one alternating-current generator. The generator or generators on a jet aircraft are connected quite similar to those on a piston type. The number of generators per aircraft will depend on the size of the electrical load and the type of electrical and electronic equipment used in the aircraft. Usually a multiengine aircraft will have two direct-current generators and two alternating-current generators, whereas the fighter type aircraft will have one each, or possibly only a single generator.

A single aircraft direct-current generator is capable of delivering 27.7 volts d.c., 400 amperes, continuously. The power system of a multiengine aircraft that is equipped with three d-c generators is capable of delivering 1,200 amperes at 27.7 volts, continuously.

Aircraft alternating-current generators are designed to deliver 115 or 208 volts a.c., three-phase, with a power rating up to 30 KVA (30,000 volt-amperes). In some installations the frequency of the alternating current ranges from 400 to 900 cycles, depending upon engine r.p.m. In other installations the frequency is regulated at 400 cycles.

If the aircraft's a-c frequency is nonregulated (400 to 900 cycles), an inverter is used to provide a-c voltage of 115/208 volts, three-phase, 400 cycles to circuits in the aircraft that are frequency sensitive. If the a-c frequency is regulated at 400 cycles no inverter is necessary. Aircraft inverters will be discussed later in this chapter.

The trend in naval aircraft is to limit the use of d-c current equipment and use more a-c equipment. Some aircraft already in use have only alternating-current generators. In these aircraft, selenium rectifiers are used to obtain direct current for electronic equipment that is designed for d.c.

DIRECT-CURRENT GENERATOR SYSTEMS

The d-c power supply for most aircraft is usually obtained from a 24 to 30 volt, single-wire system. A typical system consists of the following principal units—a 24-volt battery, an engine-driven generator, a voltage regulator, and a reverse current relay. In most installations the positive lead of the d-c system is insulated and the metal structure of the aircraft is used as a negative (ground) lead.

Figure 6-1 is a basic diagram of a single-generator d-c system which shows the connection of the main system units. Resistor *R* load represents a typical value of resistance which might be presented by the equipment deriving power from the system.

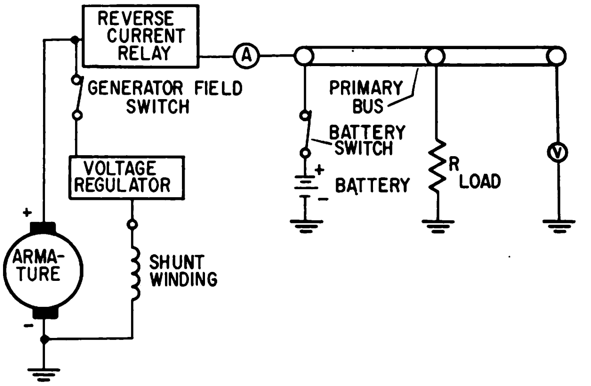


Figure 6-1.—Basic diagram of single-generator d-c supply.

The battery supply usually consists of one or more 24-volt storage batteries and is used as the source of electrical energy during lo engine speeds, for engine starting when no other source is available, or in case of generato failure. Aircraft batteries are of small capacity to save weight; consequently, the batter should not be used as a power source for tes equipment or for engine starting, unless ther is an emergency and other sources such a auxiliary power units are not available. Th battery is connected to the primary bus syste of the aircraft through a master battery switch This switch provides a means of disconnectin the battery from the aircraft electrical syste while the aircraft is idle or while repairs ar being made to the system, and of deenergizin the electrical system when a crash is imminen These switches are usually of the solenoid-typ and are located on the pilot's control panel the aircraft.

In some aircraft, two or more engine-drive d-c generators are installed which furnish th normal d-c requirements during flight and kee the battery charged.

The continuous rating of d-c generators is terms of speed range, volts, and amperes. T rated speed of a generator is the speed ran within which the machine produces the rat output voltage. The speed ranges of most ai craft generators are from 2,000 to 4,000 r.p. and from 4,000 to 8,000 r.p.m. Others are d signed to operate up to 9,000 r.p.m. with hi field currents and forced air cooling, which r sults in reduced weight and size. The armatu of the generator is coupled to the aircraft engi by a splined shaft which engages a gear asse bly. The gear ratio is step-up so that the ge erator armature turns faster than the engi

The electrical output of the generator is connected to the primary bus system through a reverse-current relay, shown in figure 6-1, which automatically connects the generator to the bus when the generator's output voltage reaches a preset value, and disconnects the generator when the output voltage drops below this value. Since the output voltage of the generator is dependent on the armature speed, the engine to which the generator is coupled must reach a certain minimum speed before the relay will close and connect the generator to the bus.

The d-c generators used in aircraft are usually designed for an output of 27.7 volts. The output voltage of the generator is determined by the armature speed, the electrical load, and the strength of the field current. Therefore, fluctuation in any of these three factors will result in variation of the unregulated output voltage of the generator. Because a constant generator voltage is required, a voltage regulator is provided to maintain a constant output voltage with varying load and speed within the normal rating of the generator. The voltage regulator accomplishes this by automatically varying the resistance in the generator field circuit, thereby varying the field current. The voltage regulator usually employed in aircraft generator systems is the carbon-pile type.

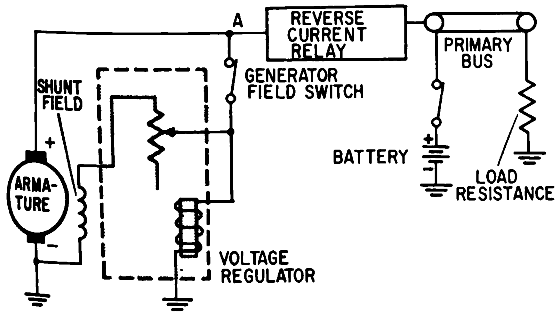


Figure 6-2.—Basic diagram of voltage regulator circuit.

The action of the voltage regulator can be understood from the circuit illustrated in figure 6-2. Basically, a voltage regulator consists of a variable resistor and a solenoid. In the figure, the variable resistor symbol represents the carbon pile. The variable resistor of the regulator is connected in series with the shunt field of the generator, and is controlled by the solenoid which is connected across the generator output circuit.

With the generator in operation and the generator field switch closed, the solenoid, which controls the position of the moving arm of the variable resistor, is connected across the generator output voltage (point A to ground). An increase in generator output voltage at A will cause more current to flow through the solenoid coil. This increased current causes the core and the moving arm to be drawn downward, increasing the amount of resistance which is in series with the shunt field of the generator. Increasing the resistance of the field circuit causes a decrease in the field current and field excitation. This results in a corresponding decrease in generator output voltage.

When the generator voltage decreases, the regulator decreases the resistance of the field circuit. Decreasing the field resistance causes an increase in field current and excitation and a consequent increase in the output voltage. Through this action the output voltage is maintained nearly constant.

ALTERNATING-CURRENT GENERATOR SYSTEMS

In aircraft power systems, a number of advantages are gained by the use of alternating current rather than direct-current power. Alternating voltages can be easily increased or decreased by the use of transformers, and hence are more flexible than d-c voltages. In a-c machines the use of brushes is minimized and the commutation troubles experienced at high altitudes are thereby reduced. A marked increase is taking place in the installation of special electronic equipment which requires an alternating-current supply. Where aircraft structure permits the use of a-c generating machines to be coupled to the engine, the installation of heavy inverters is thereby reduced or eliminated.

Since the a-c power requirements of different aircraft vary with their type and use, the a-c power supply equipment also varies. Most a-c systems provide one or more sources of 115/208-volts, three-phase, a.c. and of 115-volts single-phase a.c. When the system is connected for three-phase operation either 208 or 115 volts are available at the bus. By proper connection to the three-phase bus, 115-volt, single-phase operation is also possible. The frequency of the alternating-current supply is either 400-cycle, fixed frequency, or is a variable frequency from 400 to 900 cycles-per-second, depending upon the method of drive, coupling of the generator, and the equipment being supplied.

The source of a-c power is either an engine-driven a-c generator or inverters which are electrically-driven from the primary direct-current system. In many aircraft, where the a-c power need is large, a combination of these sources and types of power is common.

In contrast to the d-c generators, the magnetic field coils (called rotors) in most aircraft a-c generators are rotated, and stationary windings (called stators) then pick up the induced alternating currents. By making the higher voltage output windings stationary, and by rotating the lower voltage magnetic field, the use of brushes and their characteristic sparking at higher voltages is reduced. Most a-c generators in use are individually excited; that is, the magnetism of the rotating field is produced by electromagnets which obtain direct current for excitation from a small d-c generator which is connected to the same shaft as the rotor field, and which is contained within the same housing as the alternating-current portion of the machine.

In late model aircraft the a-c generator system supplies most of the electrical power required to operate the electronic equipment. It is necessary for you as an AT to become fully familiar with the a-c system of the particular type aircraft in your squadron. This will aid you in understanding the overall electrical application of power to electronic equipment. A typical single-generator a-c system is shown in figure 6-3. Some aircraft will be equipped with two a-c generators; this type installation will not be discussed at this time.

The a-c system illustrated in figure 6-3 consists of an a-c generator, a voltage regulator, a twin three-pole contactor relay, a control switch, and an a-c bus system. The a-c generator may be driven directly by the aircraft engine or it may be driven by a constant speed drive mechanism that is driven by the engine. If the a-c generator is driven by the latter method, its output frequency will be held at 400 cycles, ± 20 cycles.

The a-c generator consists of a d-c exciter, a d-c rotating field, and an a-c stator field. The d-c exciter furnishes current to the d-c rotating field; the rotating field induces a-c voltage in the stator field. By regulating the voltage output of the exciter, it is possible to control the a-c output voltage of the stator

The voltage regulator uses the a-c voltage output as a reference to control the exciter's output. The a-c output voltage is rectified by three selenium rectifiers. This rectified voltage provides a d-c current that flows through the voltage coil of the regulator. If the voltage

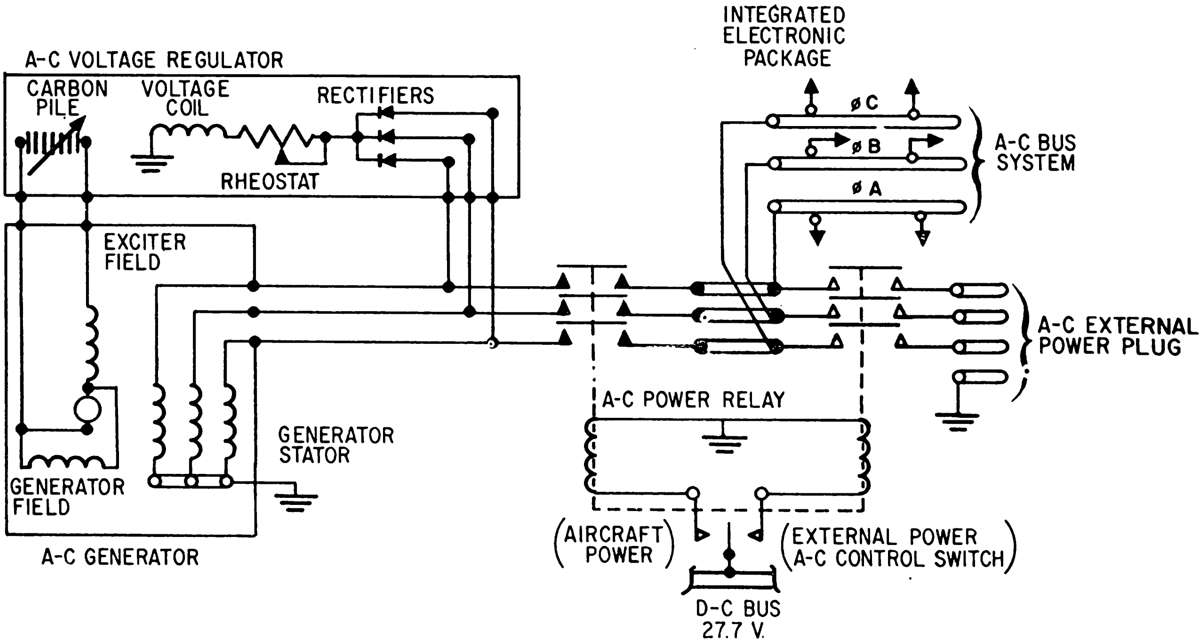


Figure 6-3.—Typical a-c generator system.

should rise above a preset amount (115 to 120 volts, single phase) current flow through the voltage coil will increase. This causes the variable resistor's resistance to increase (carbon-pile resistance), thus decreasing the a-c generator's output voltage. As the output voltage decreases, the current flow in the voltage coil also decreases. If the a-c output voltage decreases due to additional loads being applied to the a-c bus, the rectified voltage in the voltage regulator will decrease. This causes a decrease in current flow through the voltage coil of the regulator, which allows the resistance value of the carbon pile to decrease. This, in turn, allows the field current of the a-c generator to increase, causing the a-c output voltage to increase to its preset value.

A rheostat is installed on the regulator and is in series with the carbon pile's control coil. This rheostat may be used to vary the a-c line voltage 3 volts above or 3 volts below its preset value. Normally, any adjustment of this rheostat is made by the AE.

The a-c power relay provides a means of connecting the a-c generator output voltage to the buses. This relay is designed so that it is impossible to connect external a-c power to the buses while the aircraft's a-c generator is supplying voltage to them. The armatures of the relay are connected so that when one is pulled down the other is forced up. Only one coil of the relay may become energized at any one time. An a-c control switch located in the cockpit provides a means of controlling the relay. This switch has three positions—external a-c power, aircraft a-c power, and off.

The a-c bus actually consists of three separate buses, one for phase A, one for phase B, and one for phase C. From any one bus to ground 115 volts is obtained and 208 volts is obtained between any two buses. Secondary buses are energized from the primary buses, and each secondary bus has its own circuit protection.

ALTERNATING-CURRENT/DIRECT-CURRENT GENERATOR SYSTEMS

Many of the late model aircraft are not equipped with d-c generators. A-c generators are used as their main sources of power. Whenever it is necessary to have a source of d-c power it is obtained from rectifiers. These are supplied from the a-c generator. A typical rectifier unit consists of a stepdown transformer (115/208 volts a.c. to 28 volts d.c.) and a multiplate selenium rectifier. The number of plates in the rectifier determines its power output capacity.

Figure 6-4 shows a typical alternating-current/direct-current system used in a modern multiengine aircraft. By studying this figure you will be able to familiarize yourself with the units that make up a complete system.

The a-c generators are engine-driven. Each generator is controlled separately by two exciter control switches (*S*1 and *S*2) and two contactor control switches (*S*3 and *S*4). Only one generator is allowed to feed the bus at any one time—unless the system employs an a-c paralleling circuit. Each generator has its own individual a-c ammeter and wattmeter. A selector switch (*S*5) allows the use of a single voltmeter and a single frequency meter to measure the voltage and frequency of both a-c generators. As an Aviation Electronics Technician, you should always be concerned with the voltage and frequency settings prior to operating your equipment.

A switch (*S*6) labeled D-C POWER SWITCH (fig. 6-4), must be closed in order for relays *K*1 and *K*2 to become energized. These relays allow the a-c voltage from the primary a-c bus to be applied to a stepdown transformer and then to be rectified by the rectifier unit. Both buses (a-c bus and d-c bus) must be energized before all the electronic equipment will operate properly.

Both an external a-c power supply and an external d-c power supply may be used with the system shown in figure 6-4. However, in every case it is not necessary to use both types of external supplies. The a-c supply may be used to provide power to the a-c bus and also to the d-c bus through rectifier units. When this is done it is necessary that the capacity of the a-c external power source be sufficient to provide power to both buses, otherwise a separate d-c supply must also be used.

Usually the external a-c and d-c power supplies are obtained from the same unit. These units are equipped with two power cables—one for a-c voltage and the other for d-c voltage. A more detailed discussion of auxiliary power units (APU's) is given later in this chapter.

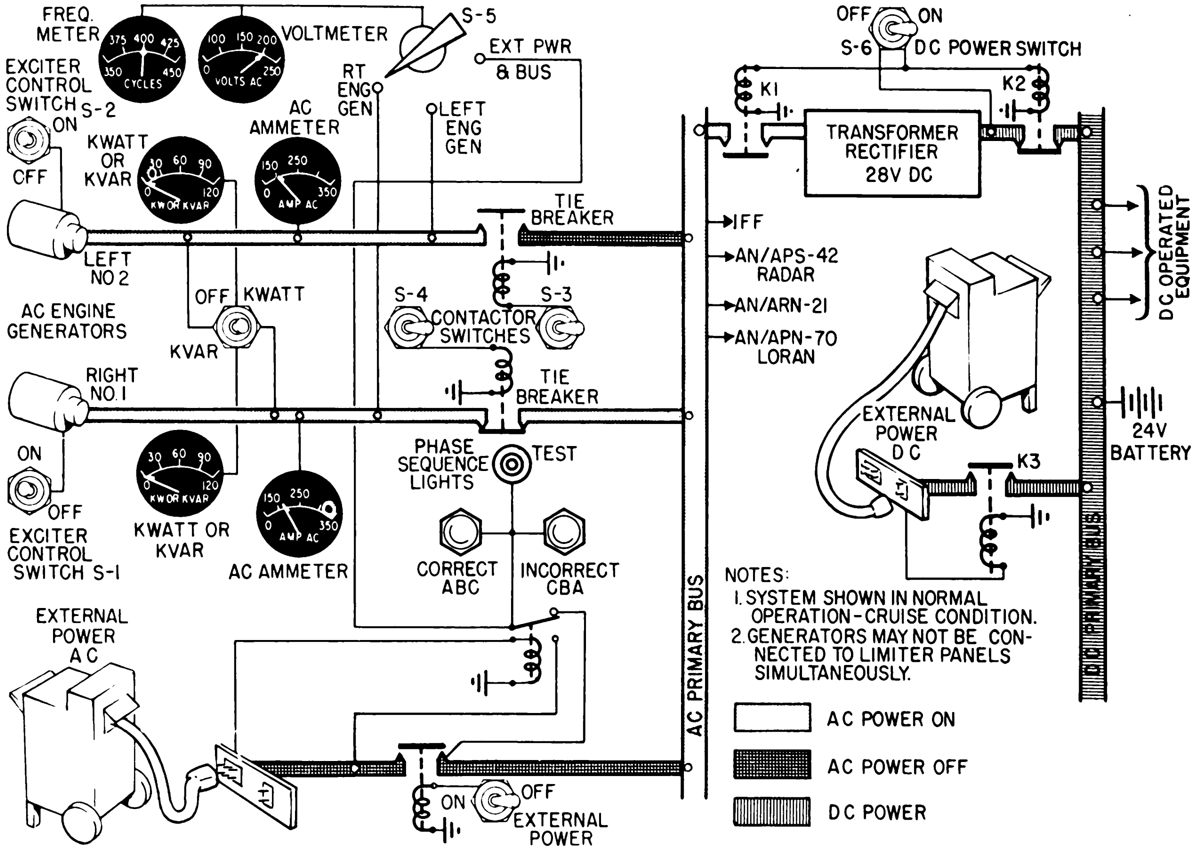


Figure 6-4.—Typical alternating-current/direct-current power system.

Aircraft Storage Batteries

The service life of an aircraft storage battery depends a great deal upon the frequency and quality of care it is given. Batteries that receive careless treatment and servicing generally have their service life ended prematurely.

The function of the aircraft storage battery is to provide a reserve source of electrical energy for operating the various units of aircraft electrical equipment. During normal engine operation, the engine-driven generator is the primary source of electrical energy, and maintains the battery in a charged state. The battery supplies power only when the speed of the engine becomes so low that the generator output voltage falls below the battery voltage. The battery also tends to eliminate the commutator ripple produced by the d-c generators.

The battery should never be used for starting engines or servicing equipment if an external power source is available. Such unnecessary usage shortens battery life and keeps the battery in poor condition to meet emergency operation requirements. During periods when the engines are idling or being started, the electrical load should be kept at a minimum.

Presently, the most common aircraft battery is the lead-acid type. However, a newer type known as the nickel-cadmium battery is being used on some aircraft. This battery is described later in this chapter.

LEAD-ACID BATTERIES

Fundamentally, there is no difference in th operation of the lead-acid aircraft batterie and automobile batteries. Both have the sam type of lead plates immersed in a solution o sulfuric acid and water and operate on the sam basic principles. The basic principles of thi type battery are covered in detail in *Basi Electricity*, NavPers 10086.

Aircraft batteries require a great deal more care than automobile batteries because of the unusual conditions under which they operate. The aircraft battery is usually shielded by enclosing it in a grounded, metal covered housing. (See fig. 6-5.) This completely shields the battery and its terminal connections. The shielding prevents radio interference from the electrical system from being radiated by the battery or any unshielded wiring.

Most aircraft batteries are equipped with a quick-disconnect unit as shown in figure 6-5. This unit is a heavy-duty connector with a handle attached to a threaded post. The battery cables can be disconnected from the battery posts simply by turning the handle and pulling the quick-disconnect unit.

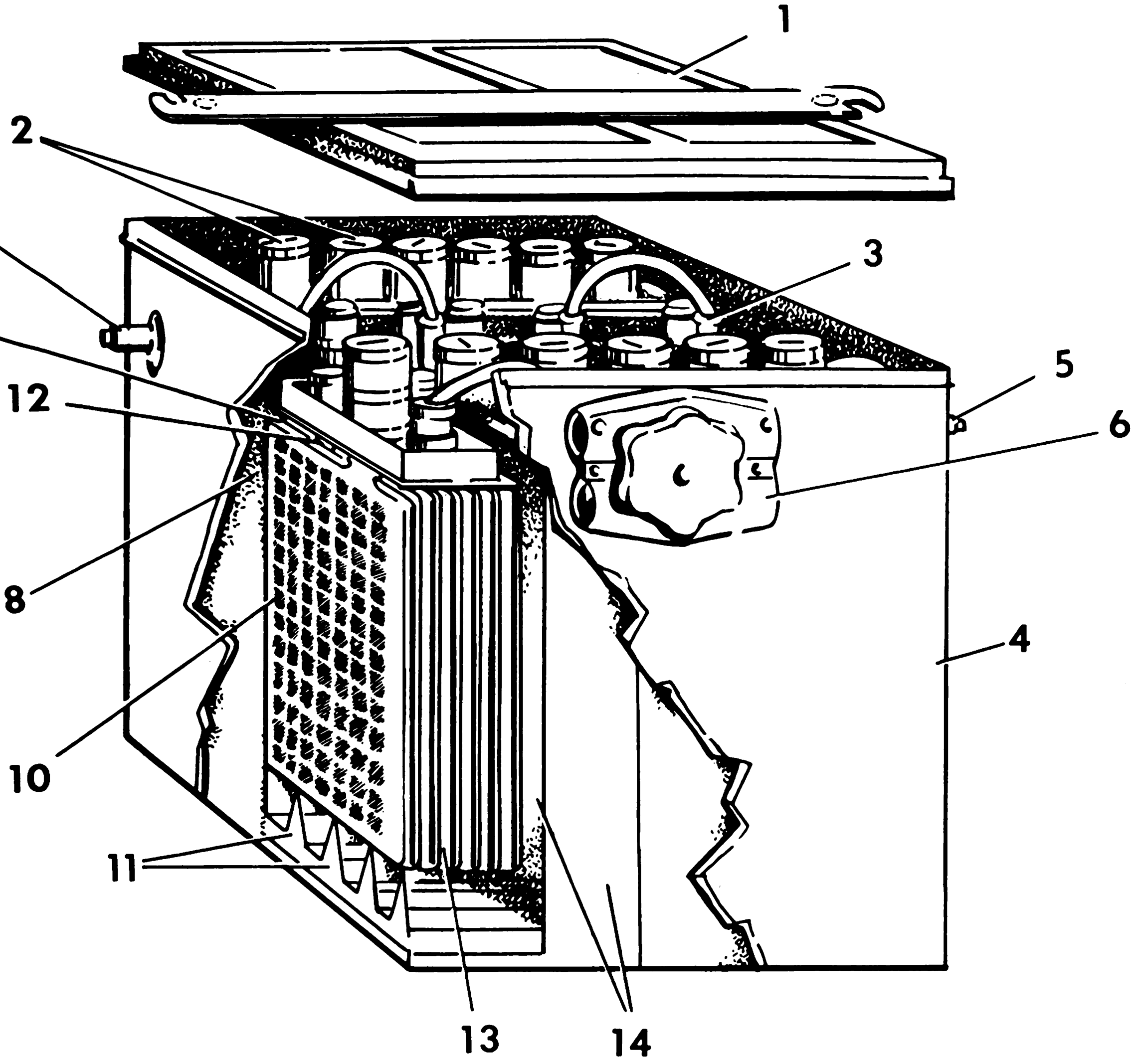


Figure 6-5.—Typical aircraft storage battery.

1. Metal cover.
2. Filler cap and vent plug.
3. Cell connectors.
4. Metal container.
5. Vent.
6. Quick-disconnect receptacle and plug.
7. Vent.
8. Cell container.
9. Positive plate group strap.
10. Plate.
11. Plate supports.
12. Negative plate group strap.
13. Separators.
14. Cells.

Aircraft batteries are built so they will not leak even when the plane is flying upside down. This is made possible through the use of "non-spill" vent plugs (caps) which contain a valve that is operated by a balanced lead weight. The valve is normally open, but when the plug is tilted through a wide angle, or inverted, the weight closes the valve.

Since it is important to keep their weight at a minimum, aircraft batteries have a small capacity. Consequently, they must be used and serviced with great care. For example, if connected to a charging voltage that is too high, an aircraft battery will overcharge in a short time. This overcharging may cause premature loosening of the active material on the plates.

When a battery is being charged, a portion of the energy is dissipated in the electrolysis of the electrolyte. Thus, hydrogen is released at the negative plates and oxygen at the positive plates. These gases bubble up through the electrolyte and collect in the air space at the top of the cell. If violent gassing occurs when the battery is first placed on charge, the charging rate is too high. The rate should never be so high that violent gassing occurs. If the rate is not too high, steady gassing, which develops as the charging proceeds, indicates that the battery is nearing a fully charged condition. A mixture of hydrogen and air can be dangerously explosive. Smoking, electric sparks, or open flames should not be permitted near charging batteries.

The specific gravity test, made with a hydrometer, indicates the state of charge. If the location of the battery permits, hold the hydrometer in a vertical position and leave the hose inserted in the cell while making the test. If the battery is located so that this is impossible, hold the hydrometer horizontally while it is filling, then pinch the hose just above the cell cover and remove the hydrometer to a position where it can be held vertically while reading. Be sure that the float is not sticking to the side of the syringe. When filling the hydrometer, draw in just enough electrolyte to raise the float from the plug upon which it normally rests. Always return the electrolyte to the cell from which it was removed.

A battery is considered fully charged if the specific gravity of the electrolyte is 1.275 or higher after temperature compensation. Cold weather operation may require a slightly higher reading. Consult the electric shop leading petty officer for specific gravity requirements for local conditions.

NICKEL-CADMIUM BATTERIES

The nickel-cadmium batteries used in naval aircraft are physically and electrically interchangeable with the present type lead-acid batteries. These newer type batteries are undergoing fleet evaluation and should they prove worthy they will find extensive use. The likelihood of their future use is so great that it is appropriate to cover this type of battery in detail in this training course. These batteries may alleviate the present problem of electrolyte leakage in aircraft lead-acid batteries, and promise to be maintenance free throughout their service life in regard to the adding of electrolyte or water.

Comparison with the Lead-Acid Battery

The nickel-cadmium and lead-acid batteries have capacities that are comparable at normal discharge rates, but at high discharge rates the nickel-cadmium batteries have higher capacities. Physically, the lead-acid battery is comprised of 12 cells with a nominal cell voltage of 2 volts, while the nickel-cadmium battery contains 20 cells with a nominal voltage of 1.3 volts per cell.

The lead-acid battery contains sulfuric acid solution (H_2SO_4) for the electrolyte, while the nickel-cadmium battery utilizes potassium hydroxide (KOH). While the lead-acid type is of the free electrolyte and free gassing type requiring adequate venting, the nickel-cadmium battery does not require any venting provisions under normal conditions. As a safety precaution, relief valves have been installed in the negative posts of each cell. This may be seen in figure 6-7. These valves release any excess gas that is formed when the battery is charged improperly. Normally, it operates withou gassing, and also most efficiently when it is not allowed to gas.

Determination of the State of Charge

At the present time there is no quick method of measuring accurately the state of charge o a nickel-cadmium battery. In an aircraft, th only practical method is to measure the ope circuit battery voltage. A charged batter should have an open circuit voltage of 26. volts or more, while a discharged battery wil normally measure 25.0 volts or less. A pre cision type voltmeter should be used for takin these measurements.

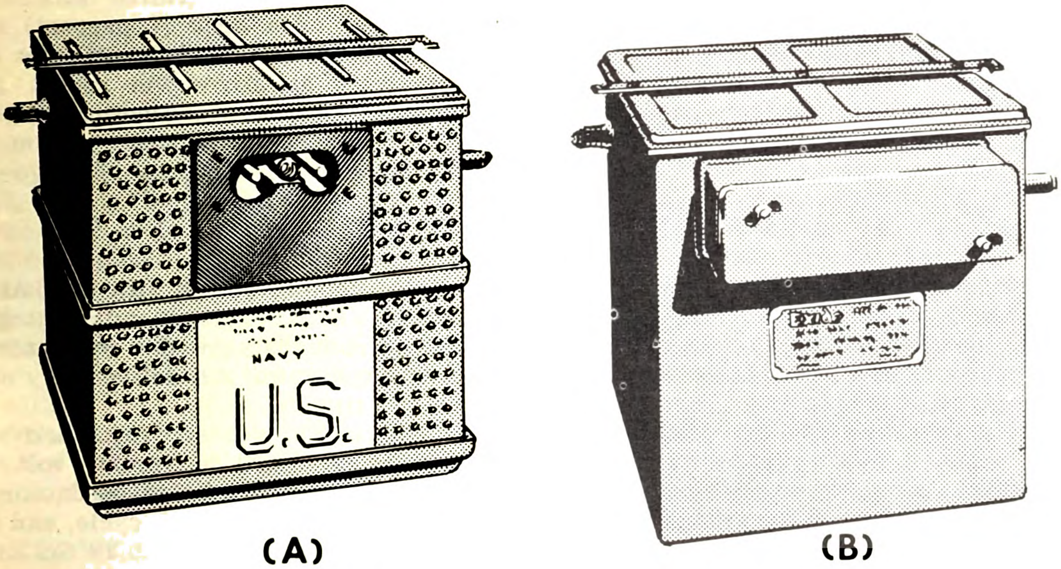


Figure 6-6.—(A) Nickel-cadmium battery; (B) lead-acid battery.

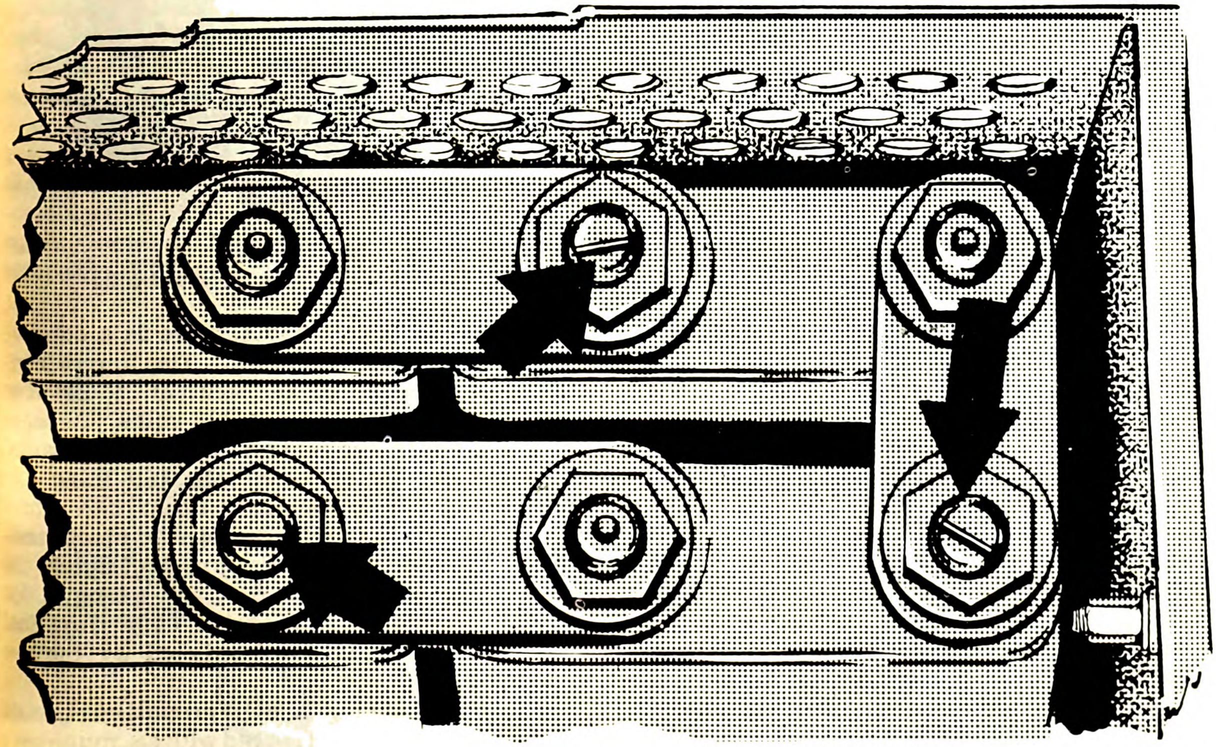


Figure 6-7.—Relief valves in negative post of cells.

Caution: The electrolyte used in these batteries is potassium hydroxide (KOH). This is a highly corrosive alkaline solution, and should be handled with the same degree of caution as sulfuric acid. If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

If KOH touches the skin, wash the affected area thoroughly with liberal quantities o fresh water and neutralize with vinegar lemon juice, or a weak (5 percent) solution of acetic acid. If the face or eyes are affected, treat as above and report immediately for medical examination and treatment.

Auxiliary Power Units

The power requirements for starting and servicing modern aircraft are very high. Even with the aircraft's batteries fully charged, their capacity is not sufficient to withstand the heavy loads of starting an aircraft.

The battery should be used for starting reciprocating engines only in extreme emergency. It should never be used for starting jets. There are many auxiliary power units (APU's) which are used for aircraft starting and for furnishing power for electrical circuits when performing operational checks on the ground.

The most widely used auxiliary power units in the Navy are the NC-5 ground self-propelled mobile power unit, the NC-6 ground power unit, the Waukesha ground power unit, and the Homelite ground power unit. Some of the larger aircraft are equipped with small auxiliary power units. They furnish power when external power or engine-driven generator power is not available. Some of these units use a gasoline engine to drive the generator while others use a gas turbine.

THE NC-5 POWER UNIT

This ground power unit is self-propelled and may be driven from place-to-place in the same manner as any other motor vehicle. (See fig. 6-8.) It has provisions for delivering three different kinds of power, each through a separate cable. This power unit will deliver up to 500 amperes of direct current at 30 volts, continuously, for servicing power purposes. It will also deliver up to 1,000 amperes of direct current at 35 volts for starting jet engines, but only for 1 minute at a time. At the end of 1 minute, during which 1,000 amperes have been supplied, there must follow an additional 1-minute period for cooling. One minute of power delivery plus 1 minute for cooling is a cycle of operation. When 15 consecutive cycles have been performed, there must follow a 15-minute cooling period with no load on th generator. Both servicing and starting power are taken from the same d-c generator; however, this generator will deliver only one typ power at a time.

In addition to d-c servicing and startin power, the NC-5 will deliver 208 volts or 11 volts a-c power through a 4-conductor cable This power is 3-phase, 400-cycle, and is use for servicing a-c equipment in the aircraft

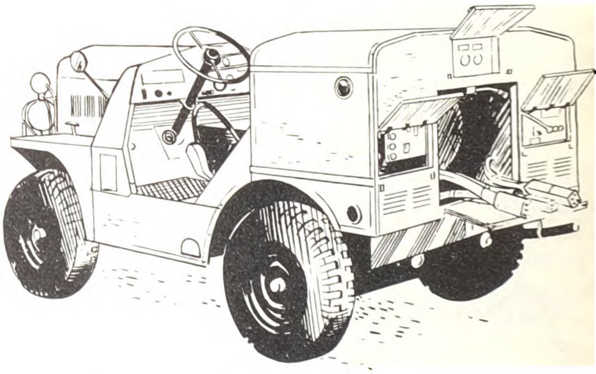


Figure 6-8.—NC-5 mobile power unit.

In the 4-conductor cable, there is a conductor for each of the 3 phases. The fourth conductor is referred to as "neutral." Betwee any 2 a-c phases there are 208 volts. Betwee any 1 a-c phase and neutral there are 115 volts

There are times when both servicing d.c and starting d.c. are needed. Since both canno be obtained from the d-c generator simultaneously, provision is made for rectifying th NC-5's a-c output into d.c. and using it fo servicing power. This is the only time tha servicing power is not furnished by the d- generator.

The NC-5, being a self-propelled groun power unit, should be treated with as much car as you would give your own automobile. Thi means that oil, water, tires, and battery wi checked periodically. Never try to operate the NC-5 unless you are a qualified and authorized operator.

THE NC-6 POWER UNIT

This is not a self-propelled unit; however, provisions are made for towing it. It consists of an 8-cylinder gasoline engine mounted on a 4-wheel body. The gasoline engine drives an a-c generator which delivers 208/115-volt, 400-cycle, 3-phase current through a cable identical to the one on the NC-5. It also supplies 28 volts d.c. with a rating of 200 amperes continuous duty. This is provided by a rectifier that is identical to the one in the NC-5 power unit.

The NC-6 is used to service equipment only; it must not be used to start jet aircraft or service any equipment that will overload it.

THE WAUKESHA POWER UNIT

This unit used a 4-cylinder, 4-stroke cycle liquid-cooled engine that is mounted on a 2-wheel pushcart. The engine drives a 300-ampere, 28-volt, d-c generator. This power unit is shown in figure 6-9.

The Waukesha power unit is used to start reciprocating engines and to provide d-c servicing power. The unit may be started either manually or electrically. The manual starting is accomplished by pulling a starting cable in one rapid movement. The electrical start is accomplished by placing the start switch on the control panel on START. As soon as the engine starts, release the start switch, and it will return to OFF (center) position. When starting, open the throttle about halfway. In cold weather it may be necessary to use the choke.

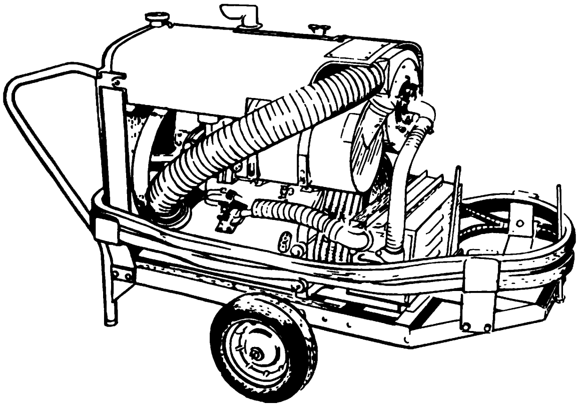


Figure 6-9.—Waukesha power unit.

Before plugging the cable of this power unit into an aircraft, be certain that all switches in the aircraft are off and that the power switch on the unit is off. After the unit is connected to the aircraft, turn on the power switch and open the throttle.

The Waukesha power unit uses a standard 24-volt, 34-ampere-hour aircraft battery to stabilize the voltage output of the generator. This battery also provides a means of electrical starting by motorizing the generator.

Before disconnecting the power unit from the aircraft turn all switches in the aircraft and the unit's power switch off. To stop the power unit's engine, pull the throttle all the way out. Never use the choke to stop the engine unless the closed throttle method fails. The Waukesha power unit should be checked for oil, water, and battery condition periodically.

THE HOMELITE POWER UNIT

This is a 1-cylinder, 2-stroke cycle engine which drives a 2,500-watt, 28.5-volt generator. It is shown in figure 6-10. This unit is used primarily for servicing power where the power requirement is not high.

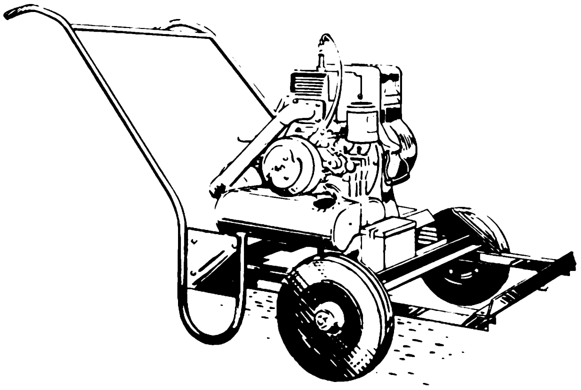


Figure 6-10.—Homelite auxiliary power unit.

A standard 24-volt aircraft battery is used for stabilizing the generator's output voltage. The battery is also used to provide extra electrical power for starting the aircraft engine. The unit itself can be started manually by pulling a cord similar to those found on an outboard motor; it can also be started electrically from its own battery. Stopping the unit is accomplished by pushing a button which grounds out the primary of the unit's magneto.

AIRBORNE AUXILIARY POWER UNITS

Some of the larger aircraft are equipped with small auxiliary power units. These may be installed at different locations on different aircraft. They are used to furnish electrical power when engine-driven generators are not operating or when external power is not available. Aircraft auxiliary power units are particularly useful on seaplanes. These planes are often moored to buoys for long periods of time during which mooring lights must be on and communications equipment used. The APU is utilized to furnish power since excessive battery usage must be avoided when possible.

Another particular application for the power units is in large landbased aircraft. Here, they are used to provide a constant voltage at a constant frequency. This is advantageous because the output of the APU is not dependent on aircraft engine r.p.m.

Some of these units use a gasoline engine to drive the generator while others use a gas turbine. Figure 6-11 (A) shows a gasoline engine-driven APU; figure 6-11 (B) shows a gas turbine drive unit.

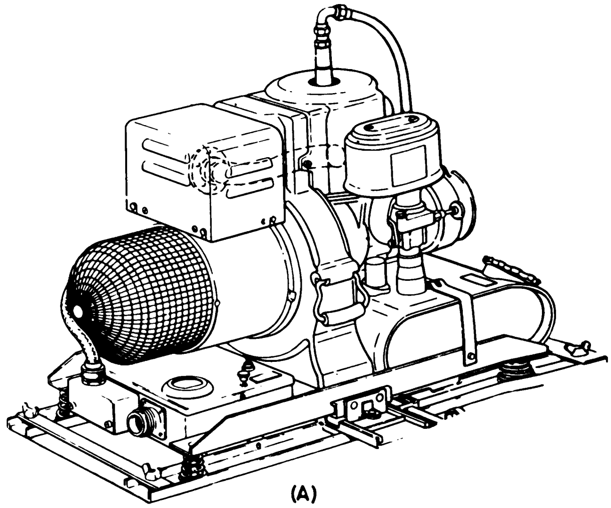


Figure 6-11.—(A) Gasoline engine-driven APU.

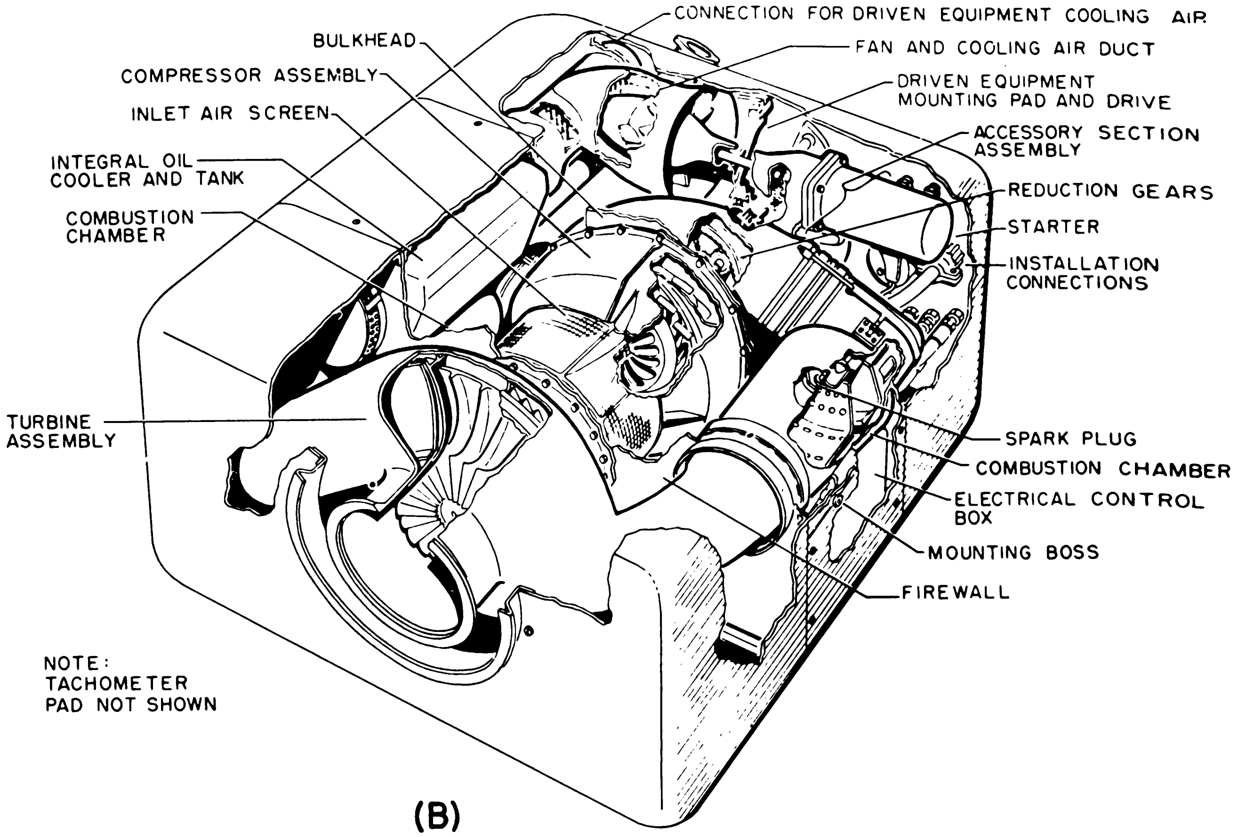


Figure 6-11.—(B) Gas turbine drive unit.

Auxiliary power unit logbooks will be kept on each power unit. The operator of the power unit is responsible for entering the operating time in the log each time the unit is used.

DECKEDGE POWER

The primary function of the deckedge low-voltage electrical system installed on most types of modern aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight deck.

Some aircraft carriers use two 600-kilowatt, 1,000-volt, 400-cycle turbogenerators for their deckedge power source. This power is reduced to the proper servicing voltage by stepdown transformers located throughout the gallery deck. Low d-c voltage for aircraft servicing and starting is obtained through specially designed rectifiers. These low voltages are supplied by stepdown transformers. The rectifiers are also installed throughout the gallery deck. This system is illustrated in figure 6-12. Distribution of power from the rectifiers to the deckedge outlets and to the aircraft is basically the same for any class of ship.

Another method of providing deckedge power, used on some aircraft carriers, is the use of specially designed motor-generator sets which are energized from the ship's main service power. Rectifiers are sometimes used instead of motor-generators.

Regardless of the method used to supply the starting and servicing power, all deckedge power systems have standard remote control switches, service outlet boxes, and portable cables; these are accessible from the flight deck. Figure 6-13 shows a typical installation found on a modern aircraft carrier.

The service outlet box contains two male plugs. One of these is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval plug provides starting power. The portable cable, for connecting the aircraft to the source of external power, has a rectangular-shaped receptacle on one end and an oval-shaped receptacle on the other. This portable cable may be used to conduct either servicing or starting power.

The aircraft is equipped with a rectangular-shaped and an oval-shaped plug. These are not always located adjacent to one another. Starting power is always supplied through the rectangular plug and servicing power through the oval plug. This is done by connecting the portable cable between the deckedge and aircraft plugs. To obtain servicing power the oval end of the portable cable is connected to the oval plug in the aircraft and the opposite (rectangular) end is connected to the rectangular deckedge plug. Starting power is obtained by switching the

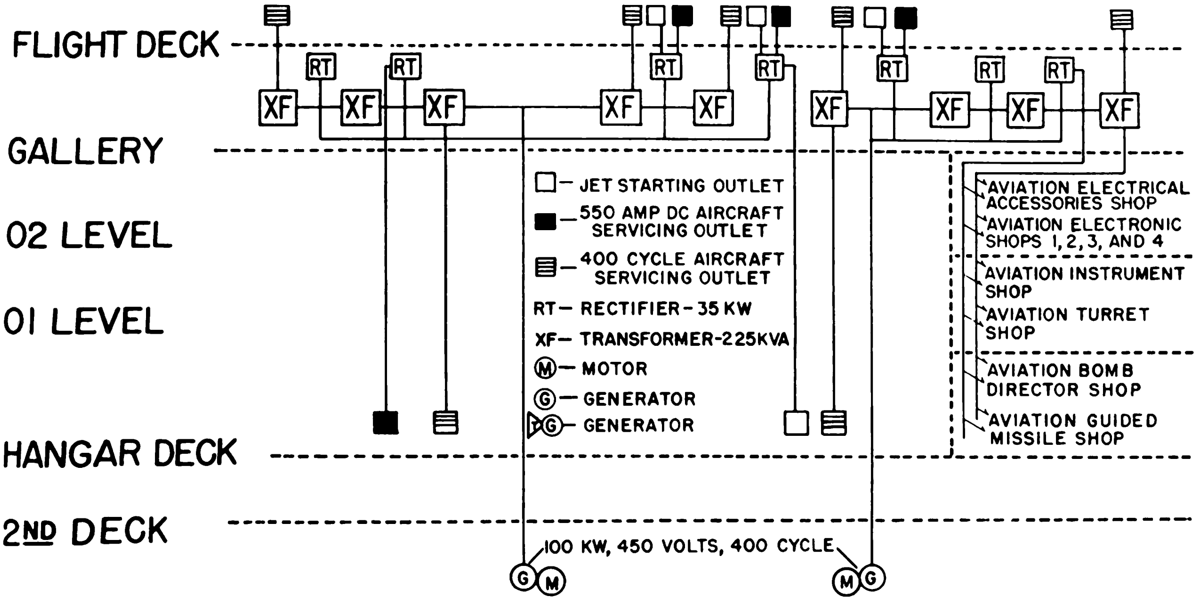

FLIGHT DECK
GALLERY
02 LEVEL
01 LEVEL
HANGAR DECK
2ND DECK
RT
XF
☐— JET STARTING OUTLET
■—550 AMP DC AIRCRAFT SERVICING OUTLET
▤—400 CYCLE AIRCRAFT SERVICING OUTLET
RT— RECTIFIER-35 KW
XF— TRANSFORMER-225KVA
Ⓜ— MOTOR
Ⓖ— GENERATOR
▷Ⓖ— GENERATOR
AVIATION ELECTRICAL ACCESSORIES SHOP
AVIATION ELECTRONIC SHOPS 1, 2, 3, AND 4
AVIATION INSTRUMENT SHOP
AVIATION TURRET SHOP
AVIATION BOMB DIRECTOR SHOP
AVIATION GUIDED MISSILE SHOP
100 KW, 450 VOLTS, 400 CYCLE
G M
M G

Figure 6-12.—Deckedge electrical system.

cable end for end and making the proper connections.

This arrangement enables you to use the same portable cable for providing either starting or servicing power. However, if both types of power must be provided at the same time, two identical cables must be used.

The cables are designed to carry 300 amperes continuously and 1,000 amperes for je starting.

Figure 6-14 illustrates how these connections may be made. To obtain servicing powe to the aircraft connect the cable from A to A to obtain starting power connect it from B to B

Circuit Protectors

The electrical system of an aircraft is protected from damage and failure by fuses, circuit breakers, and current limiters.

FUSES

The simplest overcurrent device is the fuse. A fuse is merely a short length of wire or metal ribbon within a suitable enclosed container. This ribbon (or link) is usually made of an alloy that has a low melting point and c a size which will carry a given amperage indefinitely. A larger current causes the meta to heat and melt, opening the circuit to be protected. Most fuses are made of an alloy of ti and bismuth, but copper, aluminum, Germa silver, or iron alloys have been used. A fus is always placed in series with a circuit so tha it opens the circuit automatically.

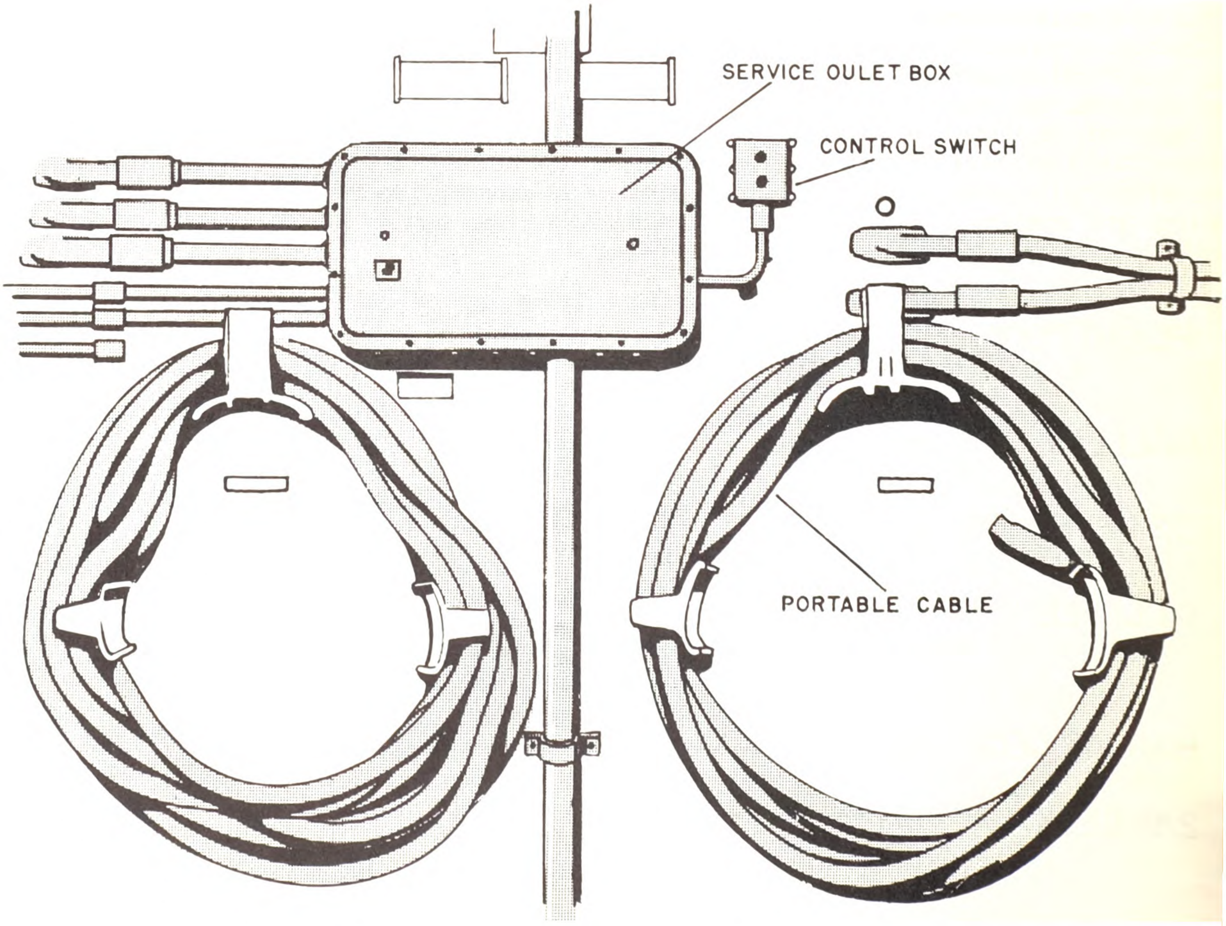


Figure 6-13.—Control switch; service outlet box; portable cable.

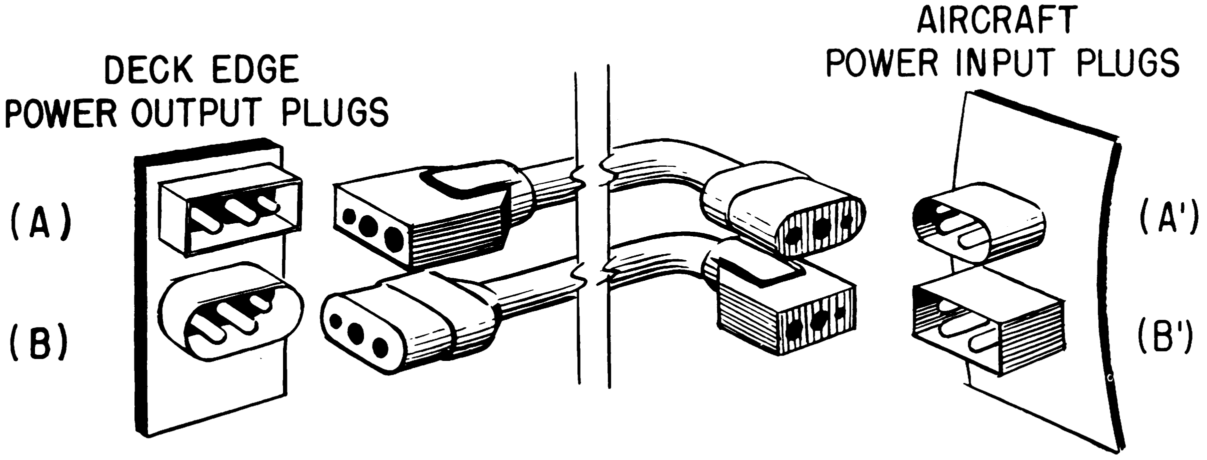


Figure 6-14.—Matching receptacles and plugs.

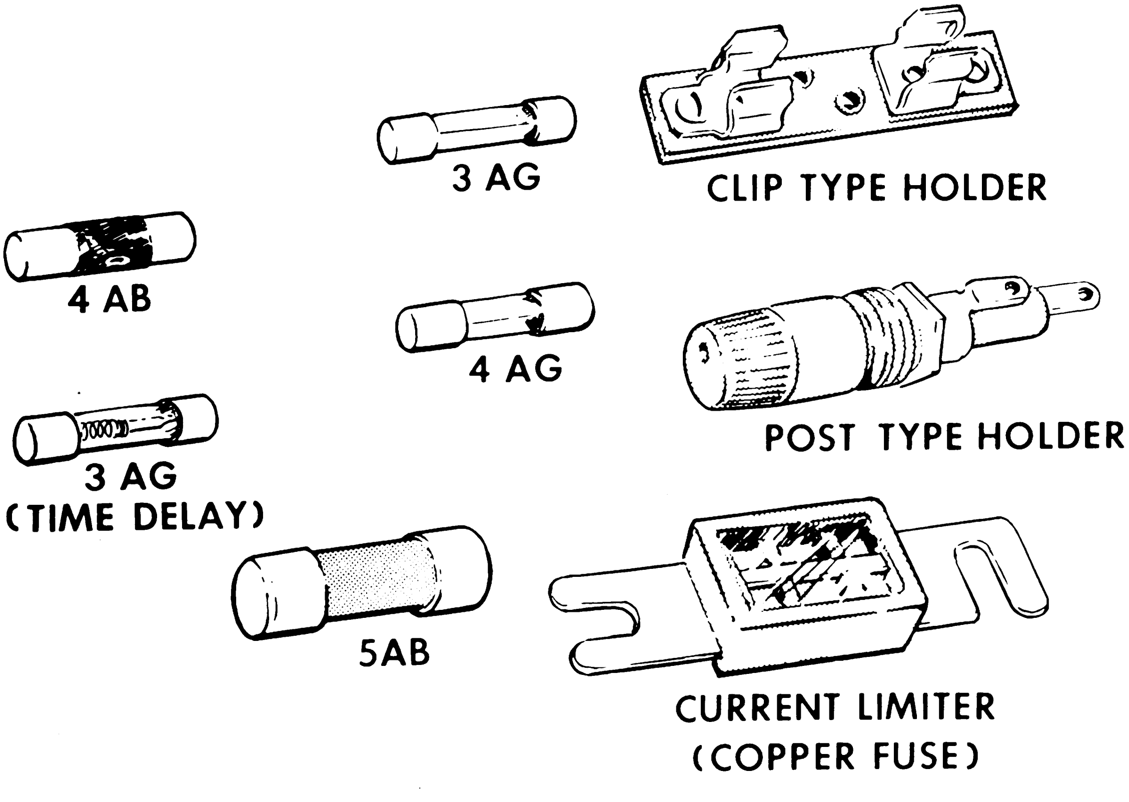


Figure 6-15.—Aircraft fuses.

The standard type fuse used in naval aircraft is the cartridge fuse. The more common types of aircraft fuses and fuse holders are shown in figure 6-15. The current capacity of each fuse is marked on the side of one of the ferrules (caps). These cartridge fuses are made in various physical sizes. The size is indicated by an AG number (such as 3AG, 4AG, etc.) which indicates a glass body and an AB number (such as 3AB, 4AB, etc.) for a bakelite body. Fuses may be further classified as instantaneous or time-delay types. The instantaneous fuse will carry its rated current indefinitely but must quickly open the circuit when its rated capacity is exceeded by about 25 percent.

Time-delay fuses are designed to have a time delay for overloads. This feature is necessary to keep short-time surges, such as high starting current for motors, from melting (blowing) the fuse. This time delay permits momentary high current without injuring the fuse, while continuous excessive current results in a rupture of the fuse. The time delay can be accomplished by making the fuse link of heavy construction except in one or two short portions of its length. This allows the heat to be drawn away from the small, high resistance portions thereby delaying the melting time.

Fuses used in aviation are not the reusable or repairable type. They must be replaced with a new fuse after the defect in the equipment has been repaired.

Another consideration in the use of a fuse is the voltage rating. This rating refers to the maximum voltage possible in the circuit in which the fuse is to be used. It is the voltage that the fuse construction can safely handle without arcing. If a fuse opens, the entire applied voltage of the circuit will appear across it. Therefore, the voltage rating of the fuse should be higher than the maximum circuit voltage.

CURRENT LIMITERS are devices somewhat similar to fuses and are used in aircraft circuits that carry high currents. (See fig. 6-15.) This circuit protector consists of a copper link of carefully predetermined sections. These sections fuse and protect aircraft power circuits when a circuit becomes shorted. For example, these limiters protect the remaining circuits of a power bus by removing the shorted circuit, thereby enabling the other circuits to function normally. It is important to replace a current limiter with the proper type since a time-delay type would not provide the proper protection in a circuit that requires an instantaneous type.

CIRCUIT BREAKERS

In most all naval aircraft today, a comparatively small device plays the role of guardian over most of the wires and cables making up the electrical system. This key to safety is the circuit breaker. It is designed to open the circuit under short-circuited or overloaded conditions without injury to itself. Thus, it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. As the fuse, the circuit breaker is also rated in amperes and voltage.

While there are three basic types of circuit breakers (thermal, magnetic, and thermomagnetic), main considerations will be directed toward the thermal type because it is at present more universally used. Circuit breakers will be divided into three categories—the pushbutton reset, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The pushbutton reset type consists of a bimetallic, thermally (heat) actuated, spring-loaded device which closes the two electrical contacts when set. This is shown in figure 6-16. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release) which releases a trigger escapement. This release permits the spring loading to rapidly separate the movable and stationary contact members.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed "tripped" position. In this position the button is fully extended and the white ring plus the inner red section of the button is showing. The latest type of pushbutton breakers have a pullout feature which permits manual opening of the circuit, but this type should NOT ordinarily be used as a switch

In place of the pushbutton actuator, a toggle lever is used on another type of circuit breaker It operates as the previously discussed breaker with the exception that the tripped position is indicated by the position of the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of use as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting there are two other classifications for cir[illegible] breakers: namely, trip-free and non-trip-[illegible] The non-trip-free circuit breakers can be maintained closed by the operator's action while a tripping condition exists. This should be done only in an emergency and since this action is apt to change the calibration of the breaker it should be replaced. This type breaker is no longer being installed in aircraft however, you may work with it on older type aircraft.

In the trip-free classes the contacts cannot be maintained closed by manually holding the

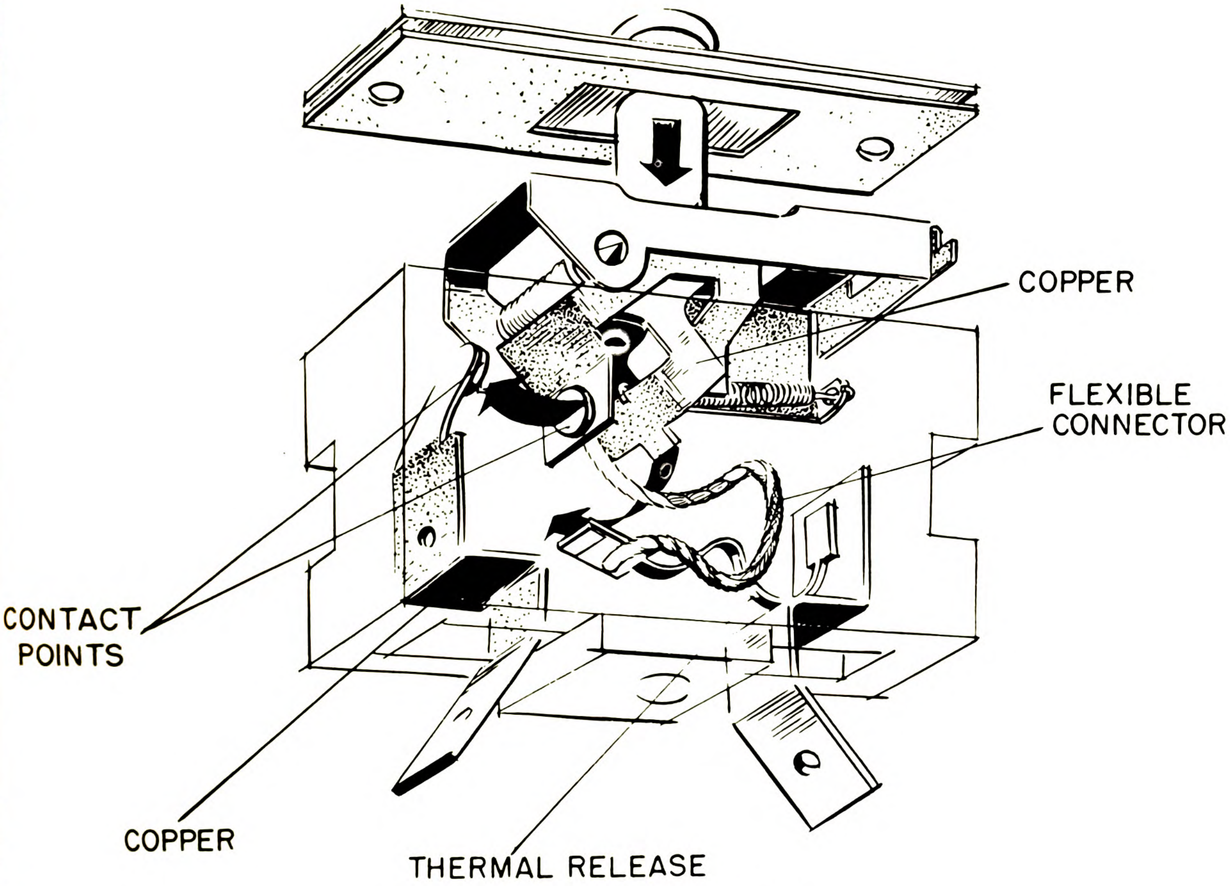


Figure 6-16.—Thermal circuit breaker.

actuator in the closed, or reset, position as long as an overload condition persists which would otherwise cause normal tripping.

Another type of thermal circuit breaker is shown in figure 6-17. This breaker consists of a conductive bimetallic snap-acting disk which bridges two electrical contacts. When this disk is heated by the excess current through it, it snaps in reverse position, opening the contacts and thereby breaking the circuit. In the circuit breakers having low ratings, a resistance wire is inserted in the circuit. The heat developed in this wire provides the heat necessary to snap the disk. These circuits are reset by pressing the button which restores the disk to its original position. Once this type of circuit breaker

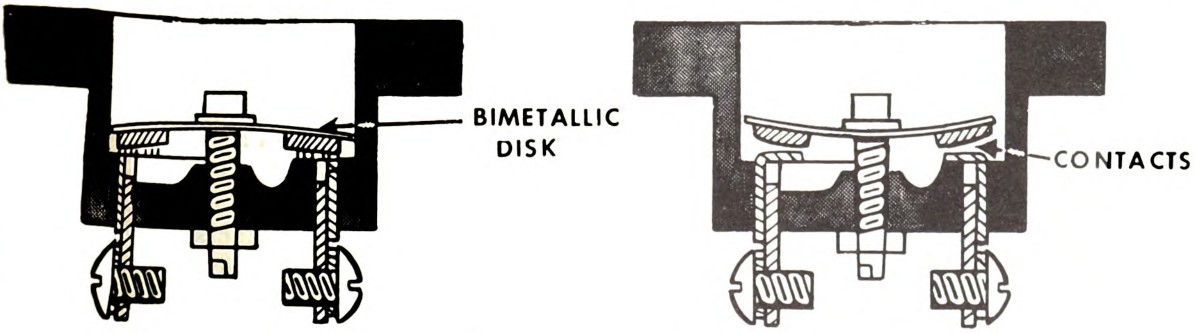


Figure 6-17.—Thermal circuit breaker.

is closed it cannot be reopened manually. They are also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.

The automatic reset type circuit breaker is similar to the bimetallic disk type just described except that it has no reset pushbutton; it resets itself automatically. After a short time, when the disk has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

Another type of circuit breaker is the switch toggle variety based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. To accomplish this, an electromagnet is placed in series with the contacts and the contacts are mounted on an armature. When an excess current flows through the device, the armature will be pulled toward the electromagnet, opening the contacts and thereby the circuit. The armature is then latched in the off or tripped position. To reset the circuit breaker, the armature is unlatched and returned to the normal position.

INSTALLATIONS AND MAINTENANCE

The maintenance of fuses is a very simple operation. When the fuse has a glass body, a visual inspection will normally disclose a open fuse. If there is any doubt as to the condition, a continuity test will readily indicate a open or closed fuse. If the fuse is defective, i MUST be replaced.

Occasionally the fuse holders will become defective. Here once again, the maintenance required is a visual inspection followed by a continuity test. If the holder is defective, i should be replaced.

Switches

A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series, all the circuit current will pass through the switch. Because it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap-action.

Many types and classifications of switches have been developed. A common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals at which current can enter the switch. The throw of a switch signifies the number of circuits each blade or contactor can complete through the switch. The number of positions indicates the number of places at which the operation device (toggle, plunger, etc.) will come to rest. Figure 6-18 presents the schematic diagrams of some often used switches.

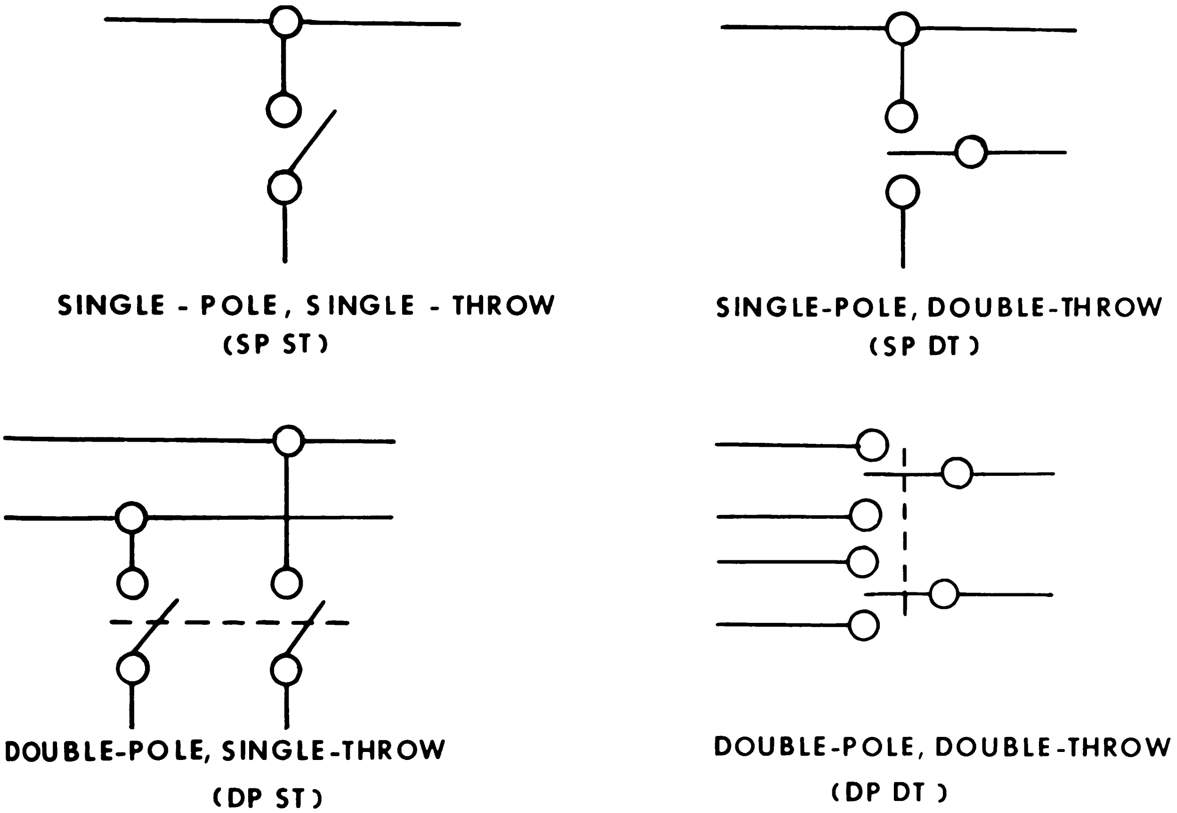
An example of a switch position is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a two-position switch. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circui is called a single-position switch. If the toggle switch will come to rest at any of three positions, it is called a three-position switch.

Another means of classifying switches i the method of actuation; that is, toggle, pushbutton, precision, and rotary types. Furthe classification can be accomplished by a description of switch action such as on-off, momentary on-off, on-momentary off, and s forth. Momentary contact switches hold a circuit closed or open only as long as the operato deflects the actuating control.

MANUALLY OPERATED SWITCHES

One of the most common types of aircraf switches is the toggle. Toggle switches hav their moving parts enclosed. A double-pole double-throw, on-off-on toggle switch is show in figure 6-19. These switches have many use and are used especially for applying power t various circuits. They are often provided wit a luminous tip on the lever so as to be visibl in the dark.

Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached t the pushbutton by an insulator. This switch i usually spring-loaded and is of the momentar contact type. These switches have many use such as indicator light checks and circuit rese Occasionally you will find the push-on an



SINGLE - POLE, SINGLE - THROW
(SP ST)

SINGLE-POLE, DOUBLE-THROW
(SP DT)

DOUBLE-POLE, SINGLE-THROW
(DP ST)

DOUBLE-POLE, DOUBLE-THROW
(DP DT)

Figure 6-18.—Schematics of commonly used switches.

push-off type of switch, but these are not common in naval aviation.

A rotary selector switch may perform the functions of a number of switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 6-20. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. Ignition switches and voltmeter selector switches are typical examples of this type.

MECHANICALLY OPERATED SWITCHES

Mechanically operated switches are used for such purposes as; radar limit switches for antenna throw, interlock switches to remove the power from the equipment when removing equipment from the case, and in the ARC-27 control box (C-1703). Many of these are the precision, snap-acting switches found in all planes. They are widely used because of their small size, light weight, and excellent dependability. The term Micro switch, although frequently used in referring to all switches of this type, is a trade name for the switches made by the Micro Switch Division of the Minneapolis Honeywell Regulator Company.

These switches will open or close a circuit with a very small movement of the tripping device (1/16 inch or less). They are usually of the pushbutton variety and usually depend upon one or more springs for their snap-action. For example, the heart of the Micro Switch is a beryllium copper spring, heat-treated for long life and unfailing action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch. The basic Micro switch is shown in figure 6-21.

The versatility of the snap-action switch is shown in figure 6-22, which shows how the basic switch may be used with different type enclosures and actuators. The particular type switching unit used depends upon the function it is to perform and environmental conditions. Figure 6-22, at top left, shows a lightweight aluminum enclosure which may contain one or more plastic-enclosed basic switches. The

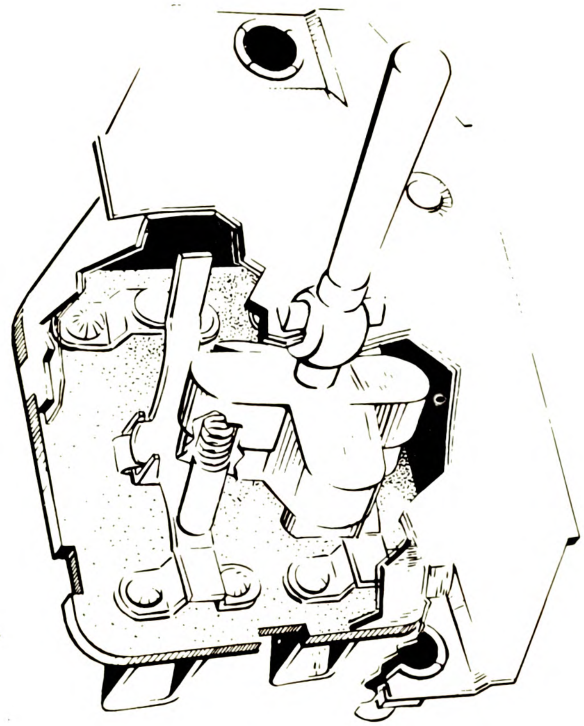


Figure 6-19.—Toggle switch.

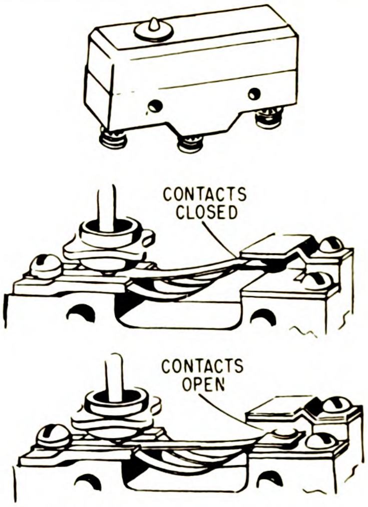


Figure 6-21.—Micro switch.

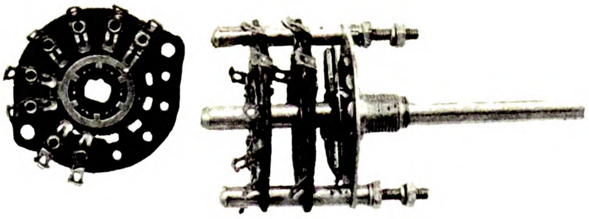


Figure 6-20.—Rotary selector switch.

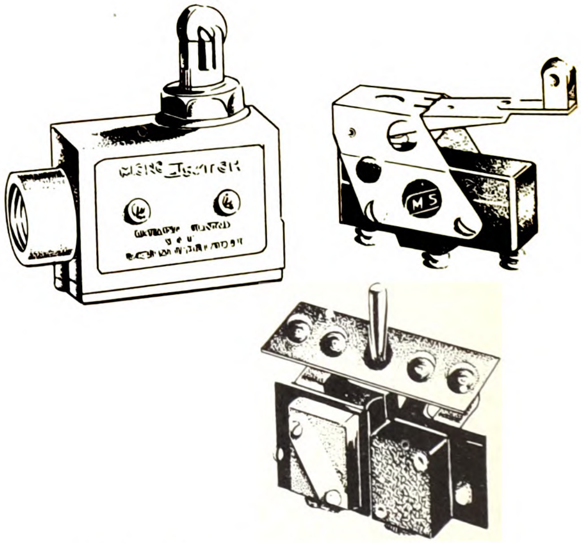


Figure 6-22.—Snap-action switching units.

plastic enclosure provides electrical insulation between the housing and the live electrical parts, support for the terminals, and a dusttight box around the electrical contacts.

Figure 6-22, at top right, shows one of the various types of switch actuators that may be used with basic switches when complete enclosures are not needed. They provide protection and mounting means. They relay the operating motion from a cam or slide to the basic switch in a way that assures long life and dependability. Figure 6-22, bottom, shows a toggle type switch which uses one or more of the basic subminiature switches. These subminiature switches are smaller than the conventional Micro switch and are finding wid use in various switching arrangements.

Pressure-operated switches usually hav Bourdon tubes, syphons, or diaphragms agains which the fluids or air operate to actuate th switch. Some low frequency transmitters us pressure switches to reduce transmitter powe at high altitude to prevent arcing.

Thermal switches usually incorporate a bi metallic sheet that bends or snaps at a desire temperature to actuate the switch. They ar used extensively as circuit breakers and als find application in controlling the igniter cir cuit on heaters and operating signal lights a critical temperatures.

MAINTENANCE OF SWITCHES

While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

When enclosed switches are used, failure to seal properly around cable openings causes most difficulty. Altitude changes permit "breathing" of moist air into enclosures with improperly sealed cable openings, and the moisture in the air may condense within the switch enclosure. The condensation can short across the switch terminals and can corrode the switch actuators in a manner that may make them inoperative. This difficulty can be corrected by careful sealing of openings or by using hermetically sealed switches. Hermetically sealed switches will also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance and open circuits.

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic-enclosed switches will eliminate this.

Some switch assemblies are equipped with adjustments which enable them to operate at a preset time or pressure. Caution should be exercised in making these adjustments; if they are not accurate, damage can result.

Relays

Relays are electrically operated switches that are classified according to their use as control relays or power relays, known as relays and contactors. The power relays are the workhorses of the aircraft's electrical system. As such, they control the heavy power circuits.

The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Where multipole relays are used, several circuits may be controlled simultaneously.

The use of relays saves space and weight in the aircraft by permitting the use of small switches at remote control stations. These switches permit the operator to control large amounts of current at other locations in the aircraft, and the heavy power cables need to be run only to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays find many other uses. With these, electron tube plate currents can control the larger currents necessary to operate electrical devices. They find frequent use in automatic relaying circuits, where a small electric signal sets off a chain reaction of successively acting relays performing various functions. Control relays can also be used in so-called "lockout" action to prevent certain functions, such as gunfiring, from occurring at the improper time. Various electrical operations in the equipment which must not occur simultaneously can be "interlocked" by control relays. Another important function of control relays in aircraft equipment is for "sensing." Control relays are used for sensing undervoltage and overvoltage, reversal of current, and excessive currents.

Another possible classification of relays is open, semisealed, and sealed. Semisealed relays have protective covers and are gasketed against entrance of salt, dust, and foreign material into the contact or mechanism area. These relays are still considered satisfactory for certain applications in present-day aircraft. Open relays are no longer used.

For other applications in today's high-altitude, high-speed aircraft, however, it is necessary to go beyond the protection offered by the open type and the semisealed relays. When such relays are used, quick changes in altitude, humidity, and temperature can cause condensation of water vapor within the unit. Subsequent low temperatures will then freeze the moisture on the contactor with a resultant inability to carry electric current.

Hermetically sealed relays were developed to answer the demands of most modern aircraft equipment. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic rubber type gasketed seals are not generally considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. There are applications where a gasket type sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more permanent. Besides being independent of altitude changes, the hermetically sealed relay also has the advantage of being protected from improper adjustments.

In general, the basic components of a relay are the coil or solenoid, the iron core, the fixed and movable contacts, and the mounting (and if sealed, the can). A manual switch, limit switch, or other small control device starts and stops the flow of current to the coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field moves a clapper or plunger which completes the magnetic circuit. Figure 6-23 (A) shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux. For a more complete analysis of the theory of operation see *Basic Electricity,* NavPers 10086.

The second basic type of relay is the rotary. (See fig. 6-23 (B).) Although this type of construction is not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. The disadvantage is that they are somewhat sluggish and requir higher operating power for many purposes The rotary relay operates on the principle o an electric motor, but through only a small arc The problem of hanging contacts on such mechanism is a difficult one, and therefore th use of these devices is limited to application where high shock warrants the larger size an weight. When used with standard wafer switc assemblies, this type of relay provides a mean for assembling a switching device of any degre of complexity.

Occasionally you will encounter relay operating from an a-c supply. These a- relays depend upon the same fundamental prin ciples as the d-c relay; that is, magnetic fields When a-c is applied to an electromagnet, th current will pass through zero twice ever cycle. Since the pull on the armature is pro portional to the current through the electro magnet, the armature tends to open every tim the current nears zero, causing chatter. T remedy this, shading coils (sometimes calle shaded poles) are used.

A shading coil consists of a copper band c stamping which is shortcircuited and embedde around part of the electromagnet pole fac By being placed around part of the pole fac it acts as a shorted transformer secondar

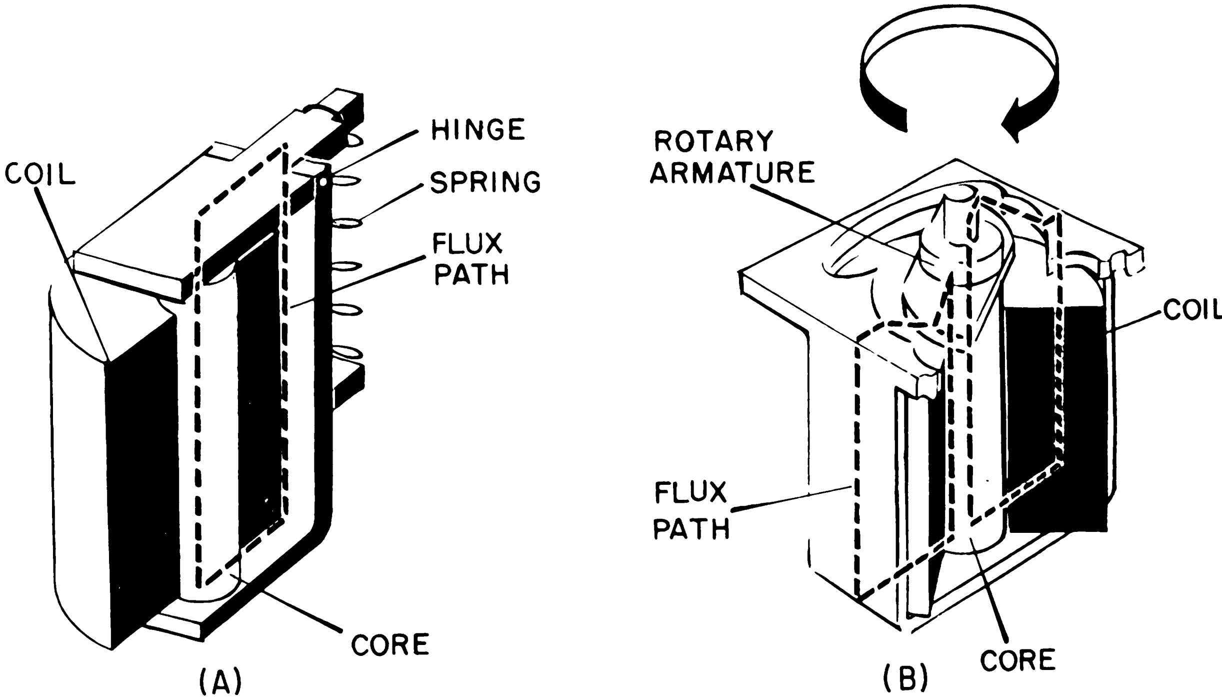


Figure 6-23.—Basic types of relays.

The current in the main coil lags the applied voltage by approximately 90° and the flux is in phase with the current. The voltage of the shading soil is induced voltage and lags the current in the main coil by 90°. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90°. This means that flux will exist in the electromagnet even when the main coil current becomes zero. Thus, chattering is prevented.

The arrangements of relay contacts are found in many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement.

It is often desirable to introduce time delays by use of relays. One method is to use a thermal relay for a time delay. The operation of this type of relay is very similar to the thermal circuit breaker with the exception that it closes the circuit rather than opens it, when heated. Due to the simple mechanism, it can be made very small and hermetically sealed, making it ideal for use in aircraft. Because the thermal relay is activated by heat, it can be used on either a.c. or d.c.

MAINTENANCE OF RELAYS

The relay is one of the most dependable electromechanical devices in use, but like any other mechanical or electrical device in aircraft equipment, relays occasionally wear out or become inoperative for one reason or another. Should relay inspection determine that a relay has exceeded its safe life, the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement because relays are rated in voltage, amperage, type of service, number of contacts, continuous or intermittent duty, and similar characteristics.

For detecting potential relay trouble during preventive maintenance the following guides are suggested: Check for charred or burned insulation on the relay and for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated, it should be replaced with a new relay of the same type. An occasional cause of relay trouble is not the fault of the relay at all, but is due to overheating caused by the power terminal connectors not being tight enough. This should always be checked during preventive maintenance.

It is recommended that covers not be removed from semisealed relays in the field. Removal of a cover in the field, although it might give useful information to a trained eye, may result in entry of dust or other foreign material which may cause contact discontinuity. What is even more serious, is that removal of the cover may result in loss of or damage to the cover gasket. This will increase the possibility of an explosion.

Inverters

Inverters are installed in aircraft for the purpose of converting low-voltage d.c. to an alternating current at a desired fixed frequency. Radio, radar, and aircraft electrical instruments are some of the equipments that require fixed frequency current. The output capacity of inverters varies depending on the equipment they are to serve; for example, low-power output for light loads and high-power output for heavy loads. Inverters designed for 250 volt-amperes outputs are used where loads are very small. Inverters with a rated output of 2,500 volt-amperes are used in installations where the loads will be greater.

Inverters are designed to deliver 115 volts, single phase or 115 volts three phase. Also, some inverters (the larger type) have outputs of 115/208 volts single phase or three phase. The frequency of an inverter is regulated to remain fixed, usually at 400 cycles ± 20 cycles.

A cutaway view of a typical inverter is shown in figure 6-24. Figure 6-25 is the wiring diagram. Make frequent reference to these when studying the operation of the inverter. Each major component of the inverter will be discussed.

The inverter consists essentially of an armature, speed-governed motor, and a permanent magnet inductor-type generator. The armature and the permanent magnet rotor are carried on the same shaft.

MOTOR

The motor operates from direct current and is a compound wound type. That is, it has one

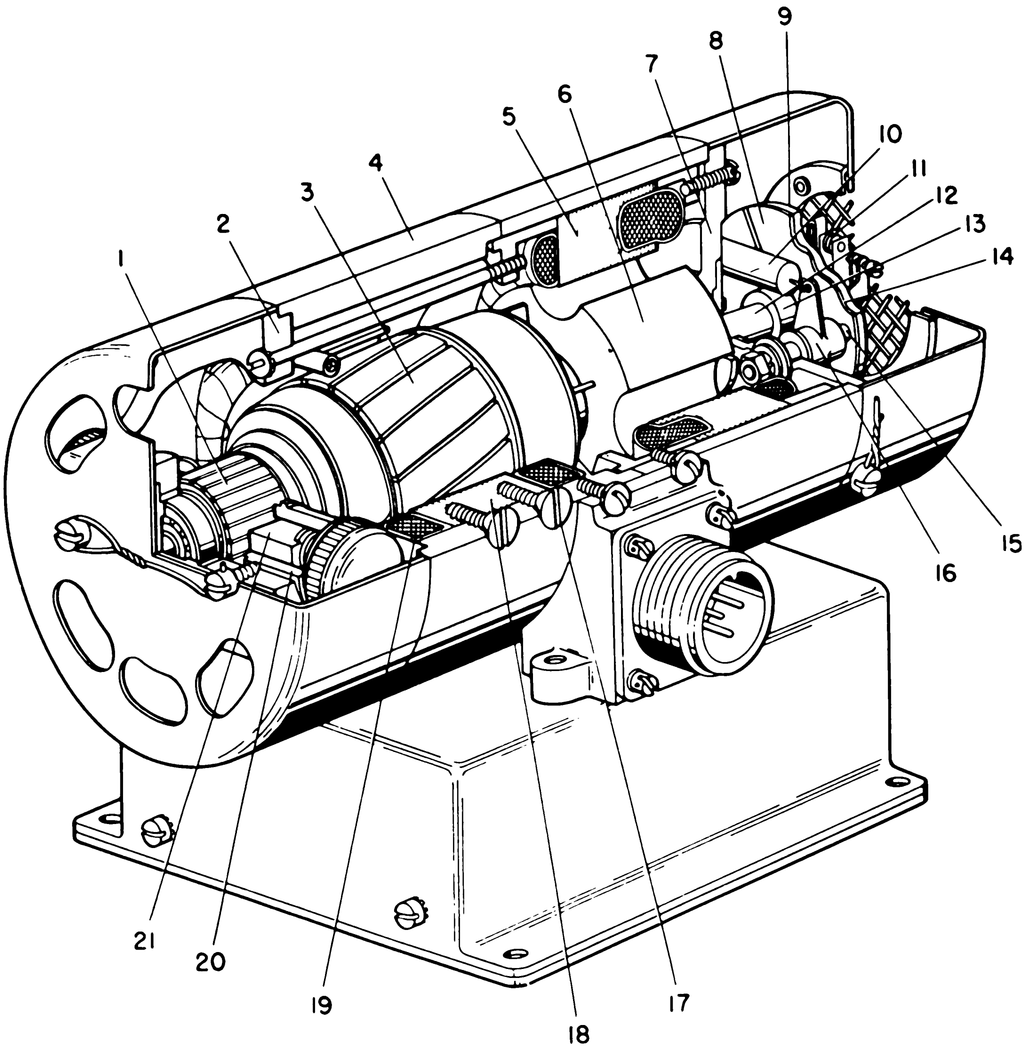


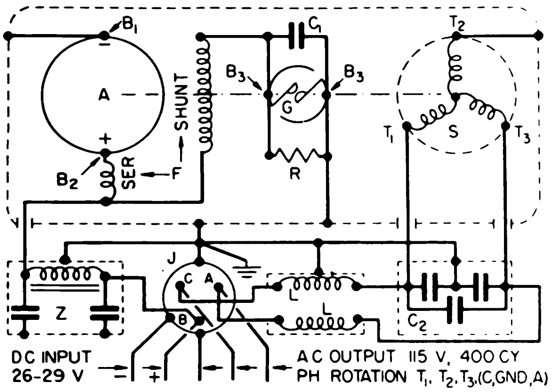
Figure 6-24.—Cutaway view of inverter.

1. Commutator.
2. Bearing brackets.
3. Motor armature.
4. Housing.
5. Stator core.
6. Rotor.
7. Bearing brackets.
8. Sliprings.
9. Insulator disk.
10. Filter capacitor.
11. Contacts.
12. Shaft.
13. Bushing.
14. Centrifugal speed governor.
15. Brush.
16. Brush holder.
17. Screws.
18. Pole shoe.
19. Field coil assembly.
20. Brush holder.
21. Brush.

set of field coils connected in parallel with the armature and one set of field coils connected in series with the armature. The compound winding provides high starting torque for low temperature operation.

The direct current divides into two branches. One branch passes through the motor shunt-field coils; the other passes through the series-field coils and armature coils. Each of these circuits is completed to ground. Th current through the shunt and series coils an the armature coils sets up magnetomotiv forces which produce a torque in the armature causing it to rotate.

The d-c input is brought into the serie windings of the field coil assembly (19, fig 6-24). It flows through the windings and into th commutator brush holder (20) and brush (21)



KEY

A —— ARMATURE ASSEMBLY
B₁ AND B₂ – COMMUTATOR BRUSH ASSEMBLIES
B₃ —— GOVERNOR BRUSHES AND SHUNTS
C₁ —— GOVERNOR NOISE SUPPRESSING CAPACITOR, 0.022 MFD., 100 VOLTS DC
C₂ —— OUTPUT VOLTAGE CORRECTING AND R-F FILTERING CAPACITOR ASSEMBLY, 3 x 0.5 MFD IN COMMON CONTAINER DELTA CONNECTED, 115 VOLTS, 400 CYCLES, AC
F —— FIELD COIL ASSEMBLY
G —— SPEED CONTROL GOVERNOR
J —— ELECTRICAL CONNECTOR RECEPTACLE
L —— R-F OUTPUT FILTER CHOKES, 3 MICROHENRIES, 0.25 OHMS
R —— GOVERNOR POINT RESISTOR
S —— ALTERNATOR STATOR ASSEMBLY
Z —— R-F INPUT FILTER ASSEMBLY, 10 AMPS, 30 VOLTS DC

Figure 6-25.—Internal wiring diagram.

Since the positive brush and negative brush contact the commutator (1), the input current flows from the positive brush, through the armature (3) coils, and into the negative brush and brush holder. Both the negative brush holder and the negative side of the power supply are grounded. The series combination of shunt-field windings and speed governor is connected in parallel with the series combination of armature coils and series-field windings, and draws energizing current from the d-c input power supply. Motor speed, which determines the a-c output frequency and voltage, is controlled by a resistor in series with the shunt field at ground potential. The resistor is cut in or shorted out of the shunt-field circuit by contacts (11) of the centrifugal governor (14) mounted on the rotor (6) end of the shaft (12).

FIELD COILS

The field coil assembly (19) consists of two field coils. Each is placed around a laminated pole shoe (18) which is secured by two screws (17) to the inside of the steel cylindrical housing (4), forming the magnet circuit. The series and the shunt windings are wrapped together in the same coil.

MOTOR ARMATURE

The motor armature (3) consists of a core, windings, insulation, and the commutator (1), mounted on the shaft (12). The core is made up of a stack of slotted iron laminations held tightly together and anchored to the shaft. The armature winding consists of coils wound in the slots of the core. The ends of the coils are connected to the commutator segments. The shaft rotates in two grease-packed ball bearings, mounted in the two bearing brackets (2) and (7).

SPEED GOVERNOR

The speed governor assembly (14, fig. 6-24) consists of two sliprings (8), an insulator disk (9), and two contacts (11). Each of the sliprings is a semicircular copper disk. They are both attached to the insulator disk, but do not contact each other. The insulator disk insulates the two sliprings from each other and also from the metal bushing (13) which contacts the shaft (12). Two brushes (15) contact the sliprings. One of the brush holders is grounded. The other brush holder (16) is insulated from ground. The shunt field is connected to the ungrounded brush holder. The ungrounded brush holder is connected through brush (15) and slipring (8) to one of the contacts (11). The other contact is grounded through the opposite slipring and brush. A resistor is connected across the sliprings, in parallel with the contacts.

Resistance in series with the shunt-field circuit decreases magnetic field strength and increases motor speed. Decreased resistance in the shunt-field circuit lowers motor speed. The position of the governor contacts with respect to each other determines the path of the shunt-field current and the strength of the magnetic field at any instant. The path may be either through the resistor or through the governor contacts and sliprings, the latter path having a relatively low resistance compared to the resistor. By this means resistance is either added to the shunt-field circuit or removed from it, and the motor speed is controlled.

When the spring-mounted contacts of the governor are closed, shunt-field current flows from one slipring to the other and the resistor is shorted out. The governor contacts open and close by centrifugal action. At rest, the contacts are in a closed position and the resistor is shorted out to result in full field strength and large starting torque when line voltage is applied to the motor. Motor acceleration is rapid, and when rotation begins, the contacts tend to open but do not actually separate until 5,000 to 7,000 r.p.m. speed has been reached. The outer spring is weaker than the inner spring. When speed exceeds 5,000 to 7,000 r.p.m., the outer spring is forced away from the inner by centrifugal action, causing the contacts to open and removes the short on the resistor.

The field current is thereby reduced and the magnet flux weakened, resulting in armature speed acceleration and creating additional centrifugal force on the springs. The contact on the inner spring is forced toward the contact on the outer spring by the increased speed. Movement of the latter is limited by the preadjusted screw top. At approximately 12,000 r.p.m. the contact on the inner spring touches the contact on the outer spring, thus again shorting out the resistor, strengthening the field and tending to reduce the motor speed. The speed does not, however, drop noticeably within the specified input voltage limits because the action is repeated rapidly to give a high degree of speed stability and minimum hunting effect. Figure 6-26 illustrates the action of the governor contacts.

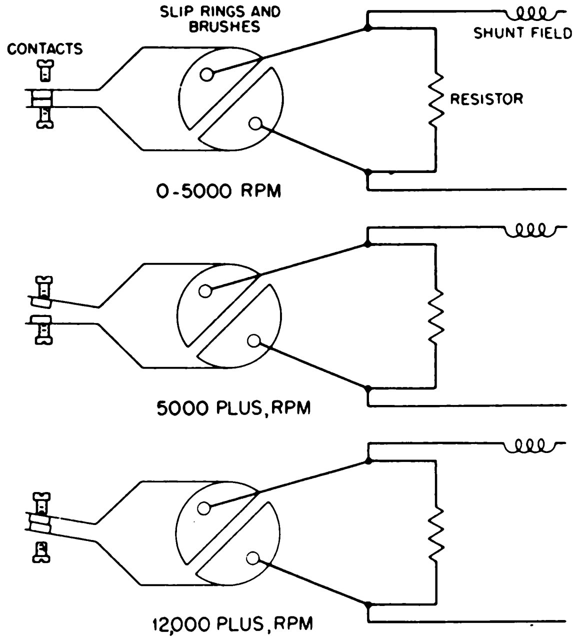


Figure 6-26.—Action of governor contacts for controlling motor speed.

GENERATOR

The generator consists of a 4-pole permanent magnet rotor (6, fig. 6-24) rotating within a 3-phase stator.

The permanent magnet creates a fixed magnetic flux in the stator core (5) when it is at rest. When the armature revolves, causing the rotor to revolve, the magnetic flux also rotates at the same rate, and cuts the conductors of the stator winding, inducing voltage in it. In a 2-pole generator, the induced voltage causes current to flow in one direction for one-half revolution of the rotor and in the opposite direction for the other half of the revolution, thus completing one cycle. In the generator of this inverter, which has 4 poles, the induced voltage changes the direction of flow 4 times, completing 2 a-c cycles per revolution. The frequency of the inverter generator voltage is determined by the speed at which the rotor magnet rotates.

The generator stator coils are 3-phase, Y-connected. They consist of 3 groups of coils connected 120 electrical and mechanical degrees apart. Therefore, 3 separate voltages are brought out through 2 leads, plus the stator frame, which is used as the third and grounded lead.

FILTERS

There are 5 filters in the inverter: a capacitor (10, fig. 6-24) across the speed governor brushes, a capacitor assembly, a filter assembly, and two RF chokes in the filter box. The capacitor (10) suppresses electrical disturbances created by the "make and break" action of the governor contacts. The RF chokes and the capacitor assembly suppress RF disturbances originating in the inverter from the a-c output circuits. The capacitor assembly also functions as a power factor corrector to adjust the output voltage to the required value. The input filter assembly consists of 2 capacitors and a choke. It prevents radiofrequency disturbances which may exist in the d-c input line from entering the inverter, and also prevents radiofrequency disturbances created by the inverter operation from being transmitted to the d-c input line.

OPERATION

The operation of the inverter is entirely automatic. There is no starting switch, load switch, fuse or circuit breaker, or other disconnecting device included in the inverter. Such auxiliaries are usually part of the equipment with which the inverter operates, or are included in the external power control circuits.

You should periodically check the inverter's frequency output with a frequency meter to assure that the frequency is within limits (400 cycles ±20 cycles). The voltage output should also be checked periodically (117 volts a.c. ±3 volts). Should the inverter require adjusting, notify the electrical division since it is the AE's responsibility to make adjustments to inverters.

In most installations two inverters are used. One is used as the main inverter and the other is used as a standby. These two inverters will never supply power to the inverter bus at the same time. Figure 6-27 shows a typical inverter power supply and distribution system.

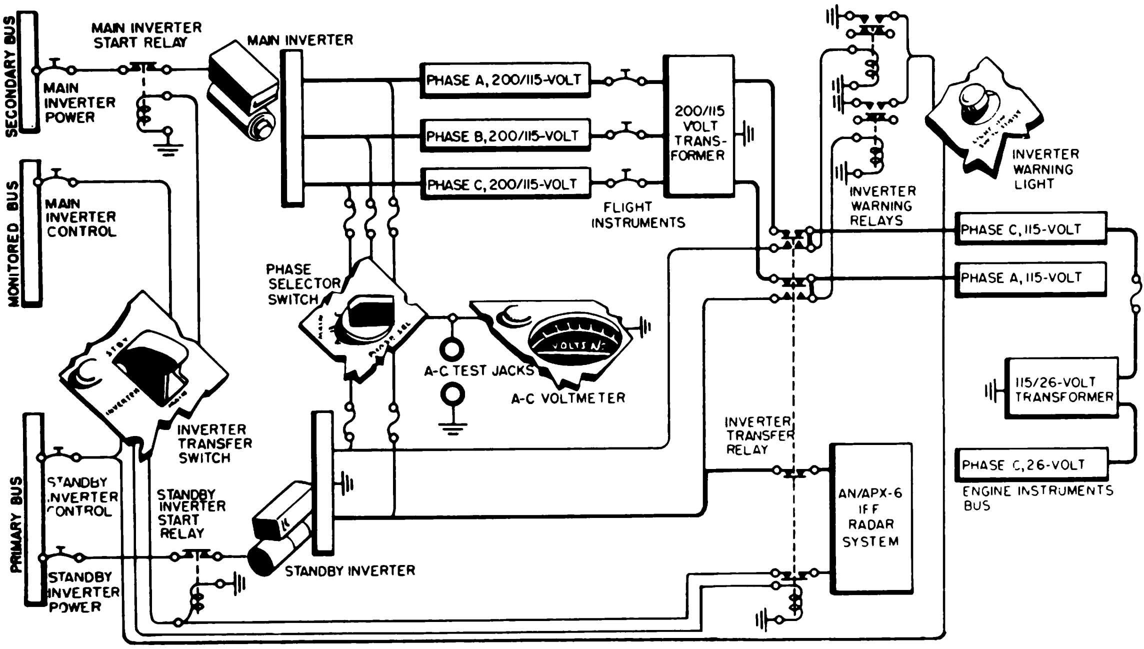


Figure 6-27.—Inverter power supply and distribution system.

Dynamotors

Dynamotors are often used in aircraft communications installations and other low-power electronic equipment. They are devices which change the low d-c voltage of the aircraft's primary power system to the higher values of d-c potential required for the operation of the equipment.

The dynamotor is essentially a d-c motor and generator mounted, or wound, on a common form and contained within a single housing. A single stationary field winding is used to provide the magnetic field for both the motor section and the generator section. The armature consists of two sets of rotor windings, both of which are wound on the same core and mounted on the same rotating shaft, but are connected to separate commutators. One winding serves to produce the driving force when energized by the low d-c potential. The other winding generates a high d-c voltage when it is rotated within the magnetic field.

A functional diagram of a typical dynamotor is illustrated in figure 6-28. The single heavy line represents the motor circuit. Relatively high current from the low-voltage source flows through the field coils and the motor winding of the armature, setting up a magnetic field around both. The coils are wound so that the fields interact and thus cause the armature to rotate.

The high-voltage winding, represented by the fine lines between the fields, is wound on

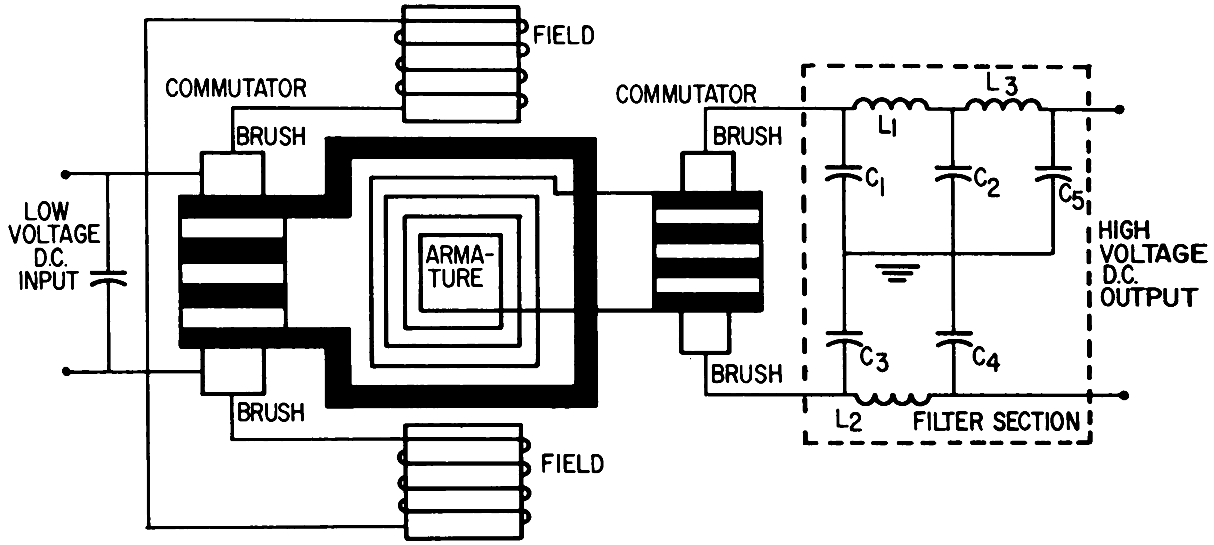


Figure 6-28.—Functional diagram of a dynamotor.

the same armature and rotates with the motor winding. When turning, the high-voltage winding cuts the lines of force of the common field, and generates a voltage which is collected by the brushes at the high-voltage commutator. The greater the number of turns in the high-voltage armature winding the greater will be the output voltage.

Since the armature and field windings in the diagram of figure 6-28 are connected in parallel the motor illustrated is a shunt-wound machine. A desirable characteristic of this type of motor is that the speed remains fairly constant during changes in the load placed upon it.

The high current drawn by the motor necessitates a correspondingly large size in the motor components, such as the commutator, brushes, and armature wire, when compared to those components of the generator. The motor commutator is larger in diameter but has fewer segments than that of the generator. The generator armature winding contains a large number of turns in order to produce high voltage, since the voltage induced in it increases with the number of turns.

Filters are usually placed at the high-voltage output terminals to filter out high-frequency currents produced by sparking between the brushes and the rotating commutator segments, thereby eliminating any possible interference from this cause. The filter consists of a combination of chokes and capacitors as shown in the typical filter section at the right of figure 6-28. The purpose of the chokes, *L*1, and *L*2, is to present a high impedance to RF energy in the external circuits. The low impedance of the capacitors, *C*1, *C*2, *C*3, and *C*4, bypass the RF energy to ground.

Additional filtering is provided to eliminate commutator ripple which is similar to the ripple found in the output of conventional a-c rectifiers. This audio filtering usually consists of a series inductor of comparatively high value and a shunt capacitor. It is represented in the figure by the iron-core choke, *L*3, and capacitor *C*5. The capacitor across the low-voltage input leads reduces sparking between the brushes and commutator at the input end of the dynamotor.

QUIZ

1. The function of a voltage regulator is to compensate for changes in
   - a. armature speed only
   - b. load on the generator
   - c. load and speed below normal generator ratings
   - d. load and speed within normal generator ratings

2. The NC-5 power unit will supply 1,000 amperes d-c current for the starting of jet aircraft. How long can this current be drawn without possible damage to the power unit?
   - a. 30 seconds
   - b. 1 minute
   - c. 2 minutes
   - d. 15 minutes

3. The motor of a dynamotor is essentially a
   - a. series motor
   - b. shunt motor
   - c. universal motor
   - d. compound motor

4. The NC-6 power unit is used for
   - a. a-c service only
   - b. jet starts and a-c and d-c service
   - c. servicing a-c and d-c equipment only
   - d. all of the above

5. Increasing the resistance in series with the shunt field of an inverter will cause the inverter's speed to
   - a. increase, because of an increased magnetic field
   - b. increase, because of a decreased magnetic field
   - c. decrease, because of an increased magnetic field
   - d. decrease, because of a decreased magnetic field

6. The primary purpose in utilizing relays is
   - a. safety
   - b. to conserve weight and space
   - c. to prevent arcing
   - d. to sense a reversal of current in the circuit

7. The motor of a typical inverter is essentially a
   - a. series motor
   - b. shunt motor
   - c. universal motor
   - d. compound motor

8. If the terminal voltage of a generator increases, the action of its voltage regulator will be to
   - a. increase the resistance of the field circuit thus increasing field current and generator excitation
   - b. increase the resistance of the field circuit thus decreasing field current and generator excitation
   - c. decrease the resistance of the field circuit thus decreasing field current and generator excitation
   - d. decrease the resistance of the field circuit thus increasing field current and generator excitation

9. The purpose of an inverter is to convert
   - a. low voltage a.c. to high voltage a.c.
   - b. variable frequency a.c. to fixed frequency a.c.
   - c. a.c. to d.c.
   - d. d.c. to a.c.

10. The number of positions of a toggle switch indicates the number of
    - a. electrical ON positions
    - b. electrical OFF positions
    - c. installation positions possible
    - d. positions in which the toggle will come to rest

11. A voltage regulator will change the
    - a. resistance of the generator field circuit
    - b. current through the generator field circuit
    - c. voltage output of the generator
    - d. all of the above

12. The explosive gas created during the charging of a lead-acid battery is
    - a. potassium hydroxide
    - b. hydrogen
    - c. manganese dioxide
    - d. oxygen

13. To prevent chattering of a relay that is being operated from an a-c source,
    - a. d.c. is used to operate the relay
    - b. the a.c. is rectified before being supplied to the relay
    - c. shading coils are used
    - d. a higher a-c voltage is supplied to the relay thus saturating the core and setting up a permanent magnetic field in the core.

14. The function of a conventional dynamotor is to
    a. convert an a-c input into a d-c output
    b. convert a d-c input into an a-c output
    c. step-up a low d-c input
    d. step-up a low a-c input

15. External power receptacles are located on the aircraft for
    a. battery charging purposes
    b. engine starting when the aircraft's batteries are weak
    c. supplying power to external circuits in an emergency
    d. engine starting and ground servicing of electrical equipment

16. Before disconnecting the Waukesha power unit from the aircraft the operator should
    a. turn all switches in the aircraft OFF
    b. turn the Waukesha's power switch OFF
    c. turn both the aircraft's switches and the Waukesha's power switch OFF
    d. stop the Waukesha's engine by pulling the throttle all the way out

17. The main advantage of the circuit breaker in comparison to the fuse is that the circuit breaker
    a. can be used as a switch
    b. is easier to maintain
    c. can be reset and used again
    d. can easily be noticed when it is in a tripped position

18. The output voltage and frequency of an inverter should be
    a. 114 to 120 volts at 400 to 800 c.p.s.
    b. 110 to 120 volts at 380 to 420 c.p.s.
    c. 110 to 120 volts at 400 to 800 c.p.s.
    d. 114 to 120 volts at 380 to 420 c.p.s.

19. The most common type of aircraft battery in present use is the
    a. lead-acid
    b. nickel-cadmium
    c. LeClanche
    d. mercury-zinc

20. The service outlet box of the deckedge electrical system contains a rectangular shaped plug and an oval shaped plug. Which of the following statements correctly describe their use?
    a. The rectangular plug provides starting power and the oval plug provides servicing power
    b. The rectangular plug provides servicing power and the oval plug provides starting power
    c. Either the rectangular plug or the oval plug can provide starting power
    d. Either the rectangular plug or the oval plug can provide servicing power

21. A charged aircraft battery should have an open circuit voltage of no less than
    a. 28 volts
    b. 26 volts
    c. 25 volts
    d. 24 volts

22. A technician that finds a circuit breaker that is continually tripping should
    a. hold the reset button in until the defective circuit is located
    b. check the circuits connected to the breaker for possible overloading
    c. replace the circuit breaker since it is undoubtedly defective
    d. do all of the above

23. The marking 4AG on a fuse indicates the
    a. size of the fuse only
    b. current capacity and size of the fuse
    c. type of body and size of the fuse
    d. type of body and current capacity of the fuse

Chapter 7

ELECTRONIC TEST EQUIPMENT

"Test equipment" is an all-inclusive phrase, encompassing test sets from the most simple to the most complex. Test equipment in general use can be as simple as a light bulb or as complex as the Beacon Simulator TDS-1172 used with the ARN-21 navigation equipment.

All electronic test equipment is designed and constructed to perform one or more specific type test. These tests are used to determine the proper operation or alinement of electronic sets, circuits, or parts. The performance of electronic units in the aircraft is determined by the accuracy of the test equipment used to calibrate and aline it and the faithfulness of the AT who performs that job. Without test equipment very few electronic devices could be used; therefore, it follows that every AT should learn to use test equipment properly.

The test equipments discussed in this chapter will be the ones currently in use in the fleet. No attempt is made to include theory beyond what is necessary to describe the operation of the test set under discussion. Whenever you use a piece of test equipment that is new to you, always consult the *Handbook of Service Instructions* (HSI) or the manufacturer's manual. These publications contain detailed and specific information on the particular equipment. Information that is presented in this chapter will not be nearly so detailed as that contained in the HSI's and the manufacturer's manuals. The purpose of this chapter is to acquaint you with the different test equipments from the standpoints of theory of operation and general operational and maintenance procedures.

Care of Test Equipment

All electronic maintenance shops are provided with a variety of test equipment to be used in maintaining the many different types of electronic units it supports. However, there are few spare test sets. For instance, a ship will normally have only one, not more than two, TS-147A test sets. When one of these becomes inoperative, shop maintenance suffers. It behooves every man to use the test equipment only for the purposes and in the manner for which it was designed. Protect the equipment from physical harm that may result from dropping, falling, or any other careless misuse, and always observe proper operating techniques.

One of the chief causes of test set failure is carelessness. The user can be careless in operating procedure or in handling the set. The usual carelessness in operating procedure is improper selection of range for the quantity to be measured, such as attempting to measure 250 volts on the 50-volt scale of a meter. If there is any doubt about proper usage of a test set, it is wise to refer to the handbook issued with the set.

Much damage to test equipment results from improper handling. Oftentimes technicians place a test set near the edge of the bench where it can easily be knocked off onto the deck or pulled off by the test leads. Common sense is the rule, and common sense means THINK. Read the instructions for proper operating procedure, and think about what you are doing while using the equipment.

CALIBRATION

Most test sets require occasional checks to determine if the set is within operating tolerances. Some sets, since they must measure up to certain frequency standards, require periodic calibration to insure optimum performance. Others are equipped to check themselves prior to their being used; an example of this is the "go, no-go" meter of the UPM-8 used with the APX-6. In every case the recommendations of the handbook or pamphlet issued with the set should be followed, unless those recommendations have been changed by a current BuAer Instruction.

Calibration is normally performed in a shop that is equipped with special-purpose test sets. It is seldom accomplished on the squadron level of maintenance.

REPAIR OF TEST EQUIPMENT

Repair of test sets is often accomplished on the squadron level of maintenance when calibration of the set is not involved. Repairs, however, are usually limited to simple ones involving replacement of test leads, vacuum tubes, meters, and any other common part. The current BuAer Instruction on repair of test equipment should be consulted before attempting any repairs of a major nature.

Multimeter

Much of your work requiring the use of a volt-ohm-milliammeter will be accomplished with a portable, battery operated multimeter. Most shops employ the TS-297 for field use (troubleshooting in the aircraft, for instance); but you, the technician, will often find the need of a more sensitive meter—one that gives more accurate readings and has wider ranges. Some equipment schematics and wiring diagrams specify that the voltages indicated at test points were obtained by using a meter of a certain sensitivity, such as a 20,000 ohms per volt meter. A meter of the same sensitivity should be used when repairing that equipment in order to obtain accurate readings. Multimeter TS-352A/U is a typical meter of this type.

MULTIMETER TS-352A/U

Multimeter TS-352A/U (fig. 7-1) is a general-purpose multirange instrument for use in circuit analysis and troubleshooting on electrical and electronic equipment. It is constructed to give accurate and reliable readings on all ranges under extreme conditions of temperature and moisture. All parts, with the exception of batteries, are sealed against the entrance of water, thus permitting measurements to be taken under adverse conditions. The batteries used with this meter are one BA-30 (1.5 volts) and three BA-31 (4.5 volts). Special temperature compensation is employed for both a-c and d-c ranges to permit use of this instrument at temperatures from -40° C. (-40° F.) to 55° C. (131° F.). A wide selection of ranges is provided to adequately measure the operating conditions of nearly any circuit.

The complete set of equipment, mounted permanently in a water resistant cast-aluminum case, includes all leads and accessories shown in figure 7-1. The main multimeter panel, which includes all electrical parts except the 5,000-volt multiplier and the batteries, is known as multimeter ME-9E/U. The multiplier which provides a 5,000-volt d-c range at 20,000 ohms per volt sensitivity is known as multiplier kit MX-815A/U. The multiplier kit is permanently mounted in a separate well in the casting, located directl above the main panel. This provides maximun safety for the operator when working with hig voltage as the voltage is dissipated within the sealed compartment. All leads and accessories are carried in a compartment built int the cover of the case. A sliding door provide access to these parts.

Operation

The panel of the TS-352A/U multimeter i laid out in such a way that all operations an functions are as nearly self-explanatory a possible. One pin jack marked -DC ± A OHMS is common to all ranges. One test lea is always plugged into this common jack an the remaining lead into the jack marked f the particular function or range desired. Th setup of the measuring circuit and meter i controlled by means of the FUNCTION switc which selects the proper circuit elements f the type of measurement desired. The desire voltage, current, or ohmmeter range is selected by a combination of rotary switch a pin jacks. The rotary switch selects the resistance or current range and the pin jac select the voltage range. Separate pin jac are provided for ohms and for the 10-ampe range. A CASE GROUND jack is connect directly to the cast aluminum case.

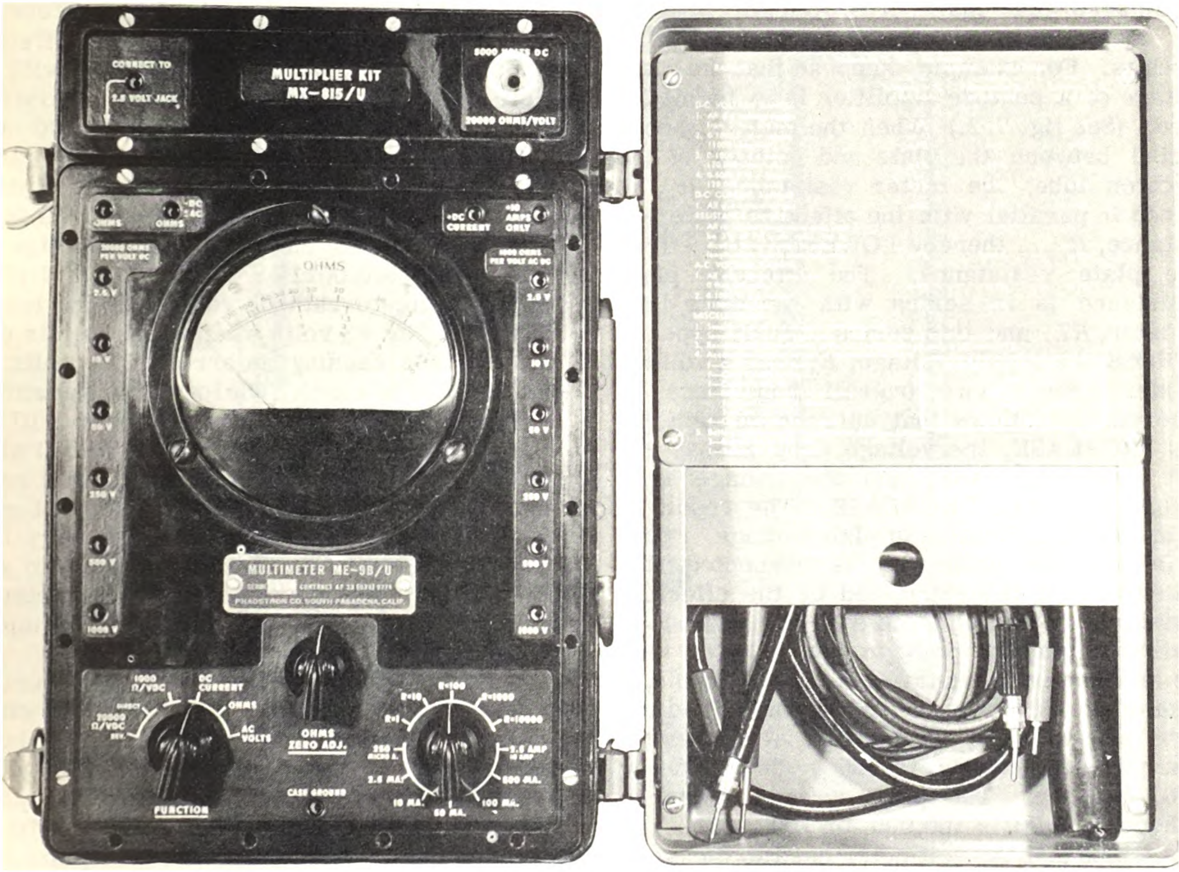


Figure 7-1.—Multimeter TS-352A/U.

The panel contains the following operating controls:

1. Function switch: This is a six-position rotary switch which is clearly marked with the type of measurement to be taken and is located in the lower left-hand corner of the front panel.

2. Range switch: This is a twelve-position switch used in selecting one of five resistance ranges or seven current ranges. This switch is located in the lower right-hand corner of the front panel. An additional current range (10 amperes) is brought out to a separate pin jack because of the magnitude of the current.

3. Ohms zero adj: This adjuster consists of a rheostat used to zero the pointer on the ohmmeter (top arc) with the test leads shorted. It also serves to compensate for variations in battery voltage, and is located in the low center section of the front panel.

Periodic Inspection

Under normal conditions, no routine ser ice inspection is necessary beyond visu examination at established inspection perio If the instrument is to be stored for peric of 6 months or longer, remove batteries prevent corrosion. This periodic inspecti should include removal of battery case cov and an inspection of battery connections. the instrument is used under extreme tempe ature conditions, a visual inspection of parts should be made at least once a mon

No periodic maintenance is required this unit except for inspection, test, and r placement of batteries.

Vacuum Tube Voltmeter

The ordinary voltmeter has several disadvantages that make it practically useless for measuring voltages in high-impedance circuits. For example, suppose that the plate voltage of a pentode amplifier is to be measured. (See fig. 7-2.) When the meter is connected between the plate and cathode of the electron tube, the meter resistance, R_m, is placed in parallel with the effective plate resistance, R_{eff}, thereby LOWERING the effective plate resistance. The effective plate resistance is in series with the plate-load resistor, *RL*, and this series circuit appears ACROSS the supply voltage, E_{bb}, as a voltage divider. Since the overall resistance is lowered, it follows that current through *RL* will INCREASE, the voltage drop across *RL* will also INCREASE, and the voltage drop across R_{eff} will DECREASE. The result is an incorrect indication of plate voltage.

Before the voltmeter is connected, the plate current is determined by the effective resistance of the plate circuit, the plate-load resistor, and the plate voltage. If the tube has an effective resistance of 100,000 ohms, a plate-load resistance of 100,000 ohms, and the plate power supply is constant at 200 volts, then the plate current is 200 v./200,000Ω, or 0.001 ampere. The plate voltage (plate to cathode) is 0.001 × 100,000, or 100 volts.

Assume that the voltmeter used to measure the plate voltage of the tube has a sensitivity of 1,000 ohms per volt and that the selected meter range is from 0 to 250 volts. The meter will then have a resistance of 250,000 ohms This resistance in parallel with the tube resistance of 100,000 ohms produces an effective resistance of 71,400 ohms in series with the plate-load resistor. The total resistance across the B supply is therefore 171,000 ohms instead of the 200,000 ohms before the meter was applied, and the current through the plate-load resistor is 200 v./171,400Ω, or 0.0011 ampere. Across the plate-load resistor the voltage drop is 0.00117 × 100,000, or 117 volts and the plate-to-cathode voltage on the tube is 200 - 117, or 83 volts when the meter is connected, thus causing an error of 17 volts (1 percent in this case). The lower the sensitivit of the meter the greater this error will be

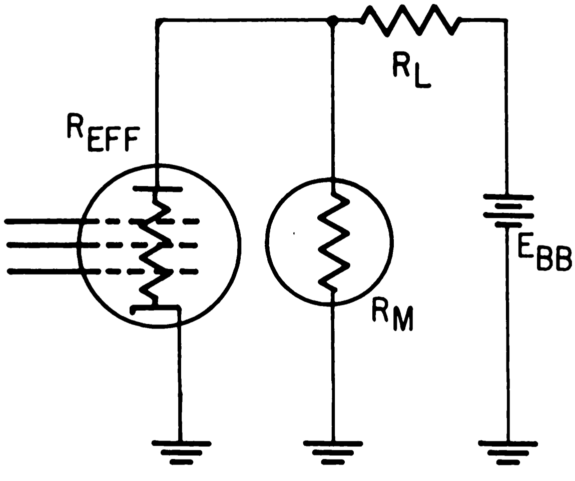


Figure 7-2.—Shunting effect created by meter resistance.

A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 percent. However, in circuits where very hig impedances are encountered, such as in gri circuits of electron tubes, even a meter o 20,000 ohms per volt sensitivity would impose too much of a load on the circuit.

Another limitation of the alternating-curren rectifier-type voltmeter is the shunting effec at high frequencies of the relatively larg capacitance of the meter's rectifier. This shunting effect may be eliminated by replacing the usual metallic oxide rectifier with a electron tube amplifier in which the plate circuit contains the d-c meter, and the voltage to be measured is applied to the grid circuit Such a device is called an electron tube voltmeter or a vacuum tube voltmeter, usuall abbreviated VTVM. Voltages at frequencies up to and greater than 500 megacycles can b measured accurately with this type of meter

The input impedance is large, and therefore the current drawn from the circuit whose voltage is being measured is small and i most cases negligible.

The disadvantage of the ordinary test mete is that it loads the circuit under test. Th main reason for using a vacuum tube voltmete is to overcome that loading effect by using meter with an extremely high input impedance A VTVM that is used extensively for electronics maintenance is the TS-505.

Figure 7-3 shows a front panel view of th TS-505. This VTVM measures d-c voltage from 0.05 volt to 1,000 volts (in 9 ranges), an a-c voltages from 0.05 volt to 250 volts r.m.s

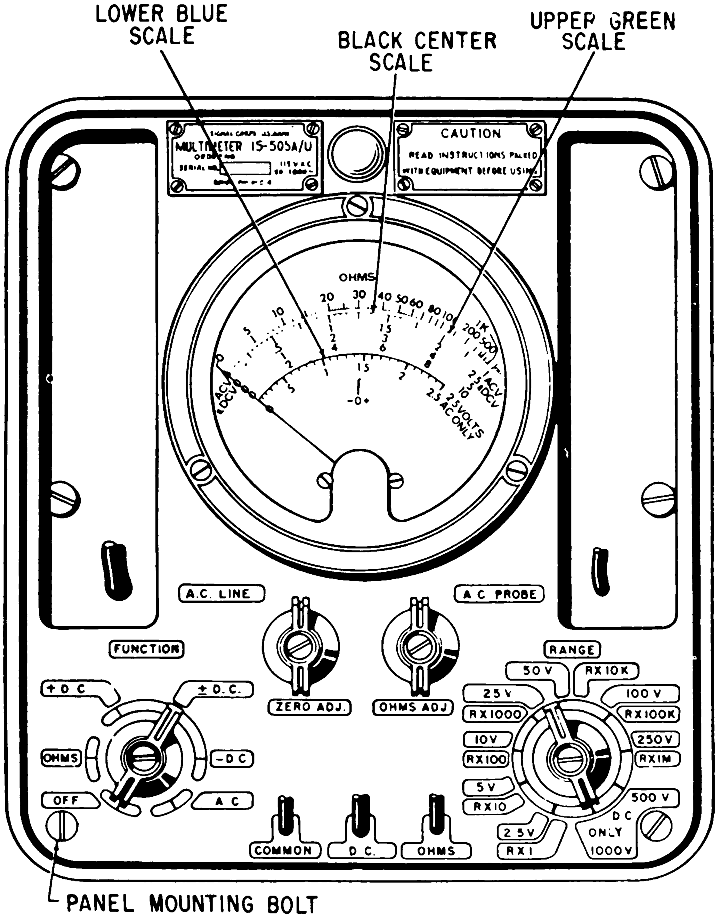


Figure 7-3.—TS-505 multimeter, front panel.

(in 7 ranges), at frequencies from 30 c.p.s. to 1 mc. With the RF adapter that is used with the d-c voltage measurement circuit, RF voltages may be measured from 0.05 volt to 40 volts r.m.s. at frequencies from 500 kc. to 500 mc. D-c resistances from 1 ohm to 1,000 megohms may be measured.

The accuracy of this meter is good, being 5 percent for d-c voltages and 6 percent for a-c and RF voltages. The meter movement requires 1 ma. for full-scale deflection.

The input impedance to the meter is 6 megohms at audiofrequencies, 40 megohms on the 1,000-volt d-c range, and 20 megohms on all other ranges.

The power requirement is 98 to 132 volts, single phase, 50 to 1,000 c.p.s., at about 21 voltamperes.

The removable cover of the TS-505 contains accessories such as alligator clips, an RF adapter, and miniature probe tips. The miniature tips slip over the regulator tips when working in confined areas.

The controls that you will use when operating the meter are as follows (refer to fig. 7-3):

1. Function switch: Selects the type of multimeter operation desired and turns the multimeter on or off.
2. Range switch: Selects various voltage or resistance measurement ranges.
3. Zero adj. control: Controls pointer of indicating meter. Used to set the meter pointer at zero on the +DC, -DC, AC, or OHM scale, or to midscale on the ± DC scale.
4. Ohms adj. control: Controls pointer of indicating meter. Used to set the meter pointer at ∞ on the OHMS scale when the FUNCTION switch is set on OHMS position.
5. Meter: Indicates the value of voltage or resistance measured.
6. AC line cord: Connects multimeter to a-c power source.

7. Common probe: Connects the ground, or common circuit of the multimeter, to the equipment under test.

8. DC probe: Connects equipment under test to the d-c measuring circuits of the multimeter.

9. Ohms probe: Connects equipment under test to the ohmmeter circuit of the multimeter.

10. AC probe: Connects equipment under test to the a-c measuring circuits of the multimeter.

11. Pilot light indicator: Lights when power is applied to the multimeter.

The operation of this meter is virtually self-explanatory. By studying the controls and their respective markings you should be able to determine the steps to follow when making a particular measurement. Do not attempt to use this instrument unless (1) you have studied the technical manual which sets forth the operating procedures or (2) you have been instructed in its proper usage, under the direction of your shop supervisor.

Two peculiarities of this meter are: (1) In order for it to indicate accurate readings it must warm up. This usually takes about ten minutes. During this period the meter pointer may drift rapidly. This is normal. (2) Voltage measurements cannot be read directly on the meter scale when the FUNCTION switch is set at the ±DC position. The purpose of the ±DC position (zero center scale) is to determine the polarity of an unknown d-c voltage or to indicate a zero d-c voltage input to the multimeter. Caution: The maximum d-c voltage which may be applied to the multimeter when the FUNCTION switch is set at the ±DC position is one-half of the voltage indicated by the panel marking opposite the RANGE switch setting.

The major difference between any VTVM and a conventional multimeter is that the VTVM utilizes a vacuum tube in its input. This vacuum tube serves as an amplifier. For a detailed explanation of the circuitry of the TS-505 VTVM consult the manufacturer's manual. The Navy Training Course *AT 1 & C*, NavPers 10318, contains a detailed description of a VTVM that is similar to the TS-505.

Tube Tester

Two types of tube testers are in general use. The emission-type tester indicates the relative value of an electron tube in terms of its ability to emit electrons from the cathode. The second and more accurate type is the mutual conductance (or transconductance) tube tester. This tester not only gives an indication of the electron emission, but it also indicates the ability of the grid voltage to control the plate current.

Several things must be considered when using a tube tester, the first being the fact that a tube tester does not give a positive indication of a vacuum tube's ability. In high-frequency applications, emission and transconductance are not necessarily of first importance in a tube's behavior, while interelectrode capacity and cathode surface resistance may be factors of prime importance. There are many requirements of a vacuum tube in special circuits, so many, in fact, that it would be impractical to construct a tube tester for field use that would check a tube for all of them.

A tube tester may be relied upon to give only a relative indication of a tube's value. Some tubes, like the 6J4W, have tested bad in a tube tester and were later found to be in good condition. An article in the NAESU Digest of July and August, 1957 explains in detail the limitations of the tube tester. It is recommended that all electronics personnel read this article.

The TV-7/U tube tester is used extensively in electronic shops. It is typical of the testers that you will use.

TUBE TEST SET TV-7/U

The technical manual TM11-5083 is issued with each TV-7/U tester. It contains complete information about the tester including schematic diagrams. Only the technical characteristics of the tester and the theory of the shorts, noise, and mutual conductance tests will be discussed in this chapter.

The TV-7/U is a portable tube tester of the dynamic mutual conductance type. It is used to test and measure the performance capabilities and to determine the rejection limits for electron tubes used in receivers, in low power transmitters, and in many other electronic equipments.

Tests that can be made on the TV-7/U are (1) dynamic mutual conductance test (for amplifier tubes), (2) emission tests (for rectifier tubes), (3) shorts test, (4) gas test (amplifier tubes), (5) noise test, (6) continuity test (ballast tubes), and (7) pilot lamp test.

The following technical data apply to the TV-7/U:

Meter range	0 to 120 arbitrary units.
Tubes	2 (1 type 83, 1 type 5Y3GT).
Power consumption	45 watts at 115 volts, 50 cycles.
Power supply:	
Voltage	115 volts ±10 volts, single phase
Frequency	50 to 1,000 c.p.s.

Tester Controls

Figure 7-4 shows the TV-7/U tester. Refer to this figure when studying the functions of the various controls which are as follows:

1. Power on-off switch (4): Controls the power input to the tester.
2. Line adjust rheostat (2): Adjusts the input voltage to the power transformer in such a manner that proper test voltages are supplied to the elements of the tube under test.
3. Filament voltage switch (5): Provides an 18-step selection of filament or heater voltages from 0.6 volt through 117 volts a.c., a BLST position to permit the testing of ballast tubes, and an OFF position.
4. Selector switches—Filament (6), Suppressor (23), Cathode (24), Screen (25), Plate (26), and Grid (27): Connect proper internal circuits to apply correct test voltages to the various pins of the tube under test.
5. Bias control (9): Adjusts to the proper value the bias voltage that is applied to the tube under test.
6. Shunt control (11): Adjusts the sensitivity of the meter circuit to the level required to test the rectifier and other diode-type tubes.
7. Function switch (22): Selects the proper meter range for the tube under test as indicated by the test data book. When this switch is set in the A position, the shunt potentiometer is connected into the circuit and must be set as indicated in the test data book. This position of the switch is used when rectifiers or other diode-type tubes are tested. The five ranges of the function switch are identified by the letters A, B, C, D, and E. The settings for proper meter sensitivity are shown in the test data book. In positions B, C, D, and E, fixed shunt resistors are connected across the meter as required. Shorts position 1 through 5 of the function switch connect the various elements of the tube under test to the shorts test circuit which contains the neon indicator lamp.
8. Eight pushbutton switches are located at the right-hand edge of the panel and are designated as follows:
   a. Line adj. test button: Depressed when line voltage is adjusted to the marker on the meter.
   b. Diode switch: Permits the testing of low-power diodes such as 6H6.
   c. Mut. cond. switch: Used to test amplifier tubes only. Should never be used when rectifier tubes are tested.
   d. Gas switches: Used when making gas tests on tubes.
   e. OZ4 switch: Used to test cold cathode rectifiers, such as the OZ4.
   f. Rect. switch: Used to test rectifiers such as the 5Y3, 6X4, and 83.
   g. Meter rev. switch: Used to reverse the polarity of voltage applied to the meter when certain types of tubes are tested. Use information found in the tube test data book.

Meter

The tester meter indicates the tube condition in arbitrary numerical units from 0 to 120. The tube test data book, mounted inside the cover of the equipment, lists the minimum numerical value of meter reading for satisfactory performance. Tubes reading below this value are not considered suitable for use in military equipment. A line test mark at midscale is used to establish the correct input voltage to the power transformer for efficient operation of the equipment.

Indicator Lamps

The pilot indicator contains a miniature lamp which glows when the power switch is in the ON position. The neon lamp serves to indicate and to locate shorted tube elements. The fuse lamp serves both as a protective fuse and an overload indicator. This lamp will flash brightly when an overload is placed on the test set or the tube under test. Turn off the equipment immediately should this lamp

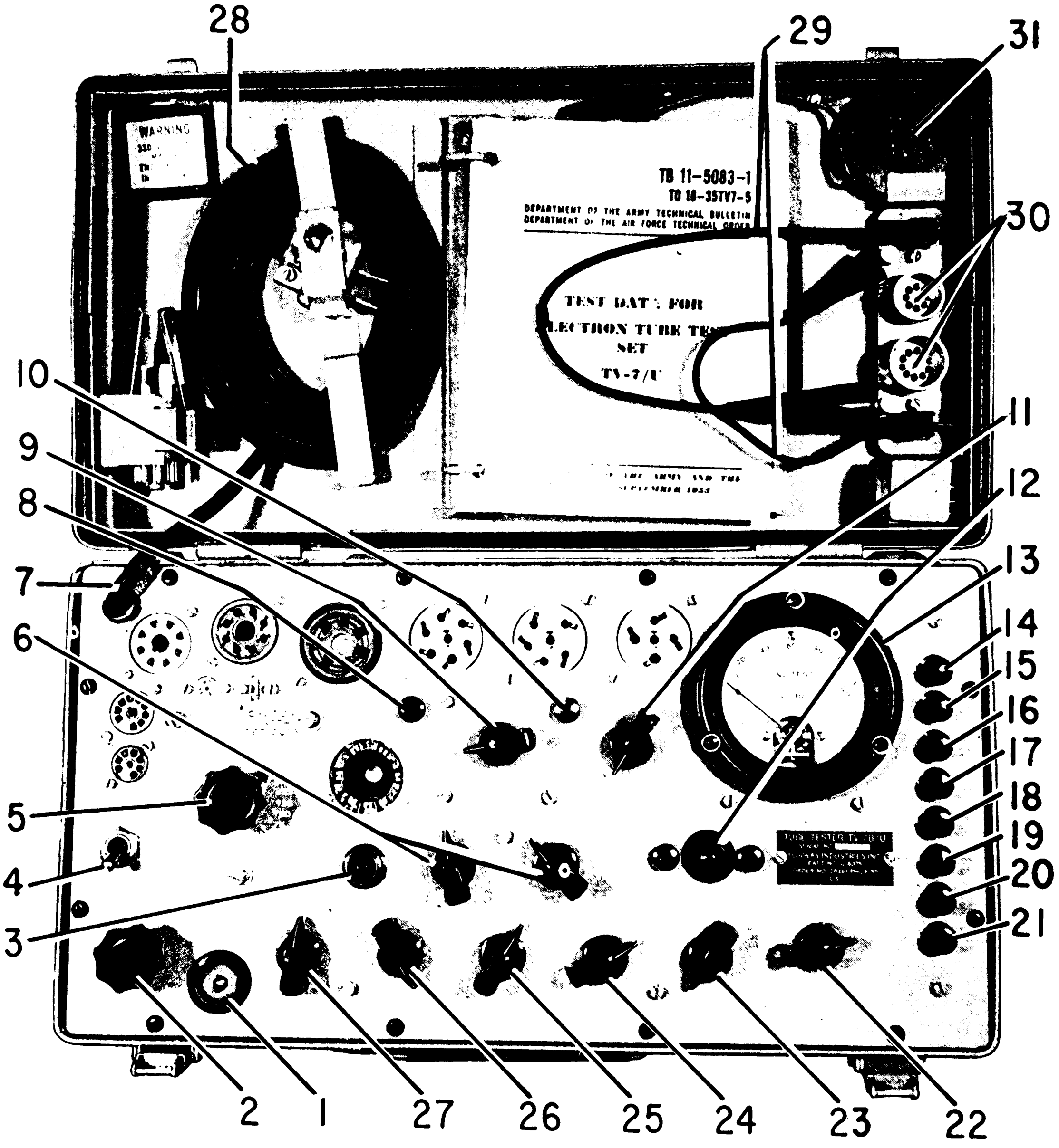


Figure 7-4.—Electron tube test set TV-7/U.

1. Fuse lamp.
2. Line adjust control.
3. Pilot light.
4. Power switch.
5. Filament voltage.
6. Filament selectors.
7. A-c line cord.
8. Grid jack.
9. Bias control.
10. Plate jack.
11. Shunt control.
12. Neon lamp.
13. Meter.
14. Meter reverse switch.
15. Rectifier switch.
16. OZ4 switch.
17. Gas 2 switch.
18. Gas 1 switch.
19. Mut. Cond. switch.
20. Diode switch.
21. Line Adj. switch.
22. Function switch.
23. Suppressor selector.
24. Cathode selector.
25. Screen selector.
26. Plate selector.
27. Grid selector.
28. A-c line cord.
29. Test leads.
30. Pin straighteners.
31. Adapter.

flash. When an overload occurs, the fuse lamp will burn out, and replacement will be necessary.

Test Sockets

Test sockets are grouped along the top edge and in the upper left-hand section of the panel. The sockets and their descriptive names are as follows:

1. Test sockets for LOKTAL and OCTAL tubes are located from left to right along the top edge. There is a combination large and small radius socket to accommodate standard 7-pin tubes and pilot lamps and sockets for 6-, 5-, and 4-pin standard base tubes.
2. Test sockets for NOVAL 9-pin tubes and 7-pin miniature tubes are located along the left-hand edge of the panel.
3. Two sockets, labeled SUB MIN, for subminiature tubes are located below the OCTAL socket. One of these sockets is for the round type and the other is for the flat type subminiature tubes.
4. The ACORN socket, designed to accommodate all tubes of this type now in current use, is located directly above the pilot indicator.

Connections

Two tip jacks, one black and one red, marked G and P, provide connections for the grid and plate test leads that are necessary to test tubes with top grid and/or top plate connections. Two black tip jacks provide noise test connections.

Two test leads are provided to make connections from the G and P panel jacks to the top caps of tubes as required. These leads are terminated on one end in a tip plug and on the other end in a battery-type clip with an insulating cover. When the leads are not in use, stow them inside the top of the case.

Three tube socket adapters are supplied with this tester. One (E105) permits the testing of type 829-B and 832-A tubes in the OCTAL socket of the test set, another (E104) provides a convenient means for testing subminiature tubes with leads instead of pins in the standard OCTAL test socket, the third is used when testing ZC39 type tubes. Secure the adapters, when not in use, to the inside of the top of the case.

Tube Test Data

A test data book is mounted on the inside of the top of the case. Information necessary to set the controls for the various tube types is tabulated in nine columns in the test data book. When using this book to position the various controls, read the headings from left to right as follows:

1. Tube types: All type numbers which the TV-7/U is designed to test are listed numerically in this column. Tubes having type letters only instead of numbers, such as XXB, are listed at the end of the numerical listing.
2. Fil.: Correct filament or heater voltages for the listed tube types are shown in this column. The filament voltage switch must be set before a tube is inserted in any of the test sockets. Unless this procedure is followed the tube may be damaged.
3. Selectors: The correct settings for the two filament selector switches and the grid, plate, screen, cathode, and suppressor selector switches are listed in this column. The settings are shown in the same order in which the switches appear on the panel, listing first the two filament selectors and then continuing from left to right with the other five selectors.
4. Bias: This column lists the proper settings for the bias dial. The bias voltage applied to the tube under test is controlled with the bias potentiometer.
5. Shunt: This column lists the settings for the dial of the shunt resistors which control the sensitivity of the meter circuit. Setting of the dial is required only when the function switch is in the range A shunt position.
6. Range: The proper settings for the function switch are listed in this column. The letters A, B, C, D, and E correspond with the range markings for the function switch.
7. Press: Under this heading are listed the correct test pushbuttons that are used for the various tube types. Multisection tubes will require different settings and different test buttons for each section of the tube.
8. Min. value: The minimum numerical values of meter indication for the various tubes and the individual sections of multisection tubes are shown in this column. Any tube showing a meter reading less than the value indicated in this column should be considered to be weak.

9. Notations: Special information pertaining to particular tube types is listed under this heading.

Basic Theory of Mutual Conductance Test

The terms mutual conductance and transconductance are used interchangeably. Either term may be defined as the ratio of a small change in plate current to the corresponding change in control grid voltage which produces it. Values of mutual conductance are expressed in micromhos. The symbol for mutual conductance is GM.

Figure 7-5 (A) is a simple full-wave rectifier circuit. This circuit will be used as a means of explaining how mutual conductance may be checked. The two power transformer secondary windings have their inner ends connected to a d-c milliammeter. A center-tapped resistor *RM* is shunted across the milliammeter. The load, resistance *RL*, is connected between the center tap of the transformer and the rectifier filament as in any other full-wave rectifier circuit. When rectifier plate 2 is positive, electron flow is through the upper half of *RM*, and the meter tends to deflect in one direction. When plate 1 is positive, electron flow is through the lower half of *RM*, and the meter tends to deflect in the opposite direction. With the load resistance fixed and equal forces acting on the meter in both cases, the pointer of the meter indicates zero. It cannot follow the variations at the rate of the power line frequency because of the inertia of the movement.

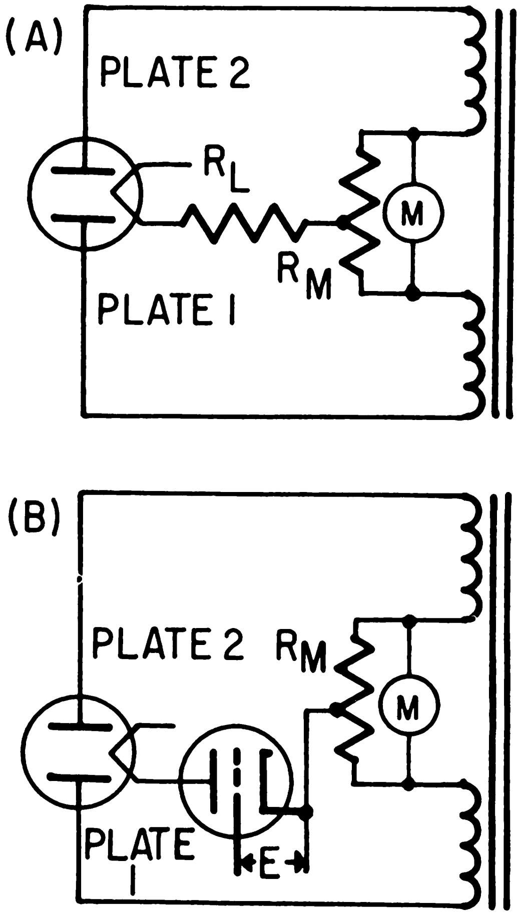


Figure 7-5.—(A) Rectifier diagram; (3) basic mutual conductance circuit.

If the tube to be tested is substituted for the fixed load resistance and a fixed bias E is applied to the tube (fig. 7-5 (B)), the meter will still read zero because the tube under steady-state conditions acts like a fixed resistance.

If, in addition to the d-c bias, an a-c potential is applied to the grid of the tube under test, the circuit becomes equivalent to the one that is employed for quality and mutual conductance tests in the TV-7/U tester. When the a-c potential swings the grid positive, the plate current of the tube is increased, the plate-cathode resistance is lowered, more current flows through RM, and the deflecting force on the pointer of the meter is greater than before the a-c potential was applied. When the grid swings negative on the other half-cycle, the resistance of the tube under test is increased and the deflecting force on the pointer of the meter is smaller. With unbalanced currents on adjacent half-cycles and consequent unequal forces applied to the pointer of the meter, the deflection of the meter becomes proportional to the difference in currents. Since this difference is created by the difference of a-c potential applied to the grid, the meter indicates the plate-current changes produced by the applied grid voltage change; or in other words, the deflection of the meter gives a measure of the mutual conductance of the tube under test.

Shorts and Noise Test Circuit

When a tube is being tested for shorts, voltage is applied from the power transformer to the various elements of the tube through

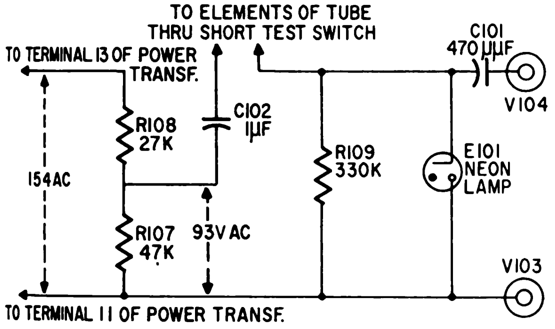


Figure 7-6.—Simplified shorts and noise test circuit.

capacitor C102. (See fig. 7-6.) The power transformer applies an a-c potential of approximately 154 volts r.m.s. to voltage divider resistors R108 and R107. A voltage of approximately 93 volts r.m.s. is developed across R107. This voltage is applied to the elements of the tube under test through capacitor C102 and neon short test lamp E101 which is shunted by resistor R109.

When testing a tube for shorts, set the selectors correctly for the particular tube. When the function switch is turned from position 1 through position 5, the various elements of the tube under test are connected between neon lamp E101 and capacitor C102. Any shorted portion between the elements will complete the circuit through capacitor C102 to neon lamp E101 and will cause the lamp to glow. This indicates a short.

The shorts test circuit (fig. 7-6) may also be used for making a noise test of electron tubes. When making this test, connect the noise test jacks J103 and J104 to the antenna and ground posts of a radio receiver. Turn the function switch from position 1 through position 5; tap the tube under test lightly with your finger or with the eraser end of a pencil. Intermittent disturbances between the electrodes that are too brief to register on the neon lamp establish a momentary short, permit the alternating voltage from the power supply to be applied to the neon lamp, and cause a brief oscillation. This oscillation is reproduced by the loudspeaker or headphones as an audible signal. By using a receiver in this manner the noise generated by the tube under test is amplified to an audible level.

Oscilloscope

An oscilloscope is an electronic test set that displays information on the face of its cathode ray tube. It is sometimes referred to as an "O" scope. The uses of an oscilloscope are many and varied, but you will use it primarily to troubleshoot and aline electronic equipment. This will be accomplished by observing and analyzing waveforms as to shape, amplitude, and duration. The *Handbook of Service Instructions* for the particular set of electronic equipment on which you are working will designate what waveforms are to be observed at various test points throughout the set. Waveforms that will be observed from the same test point will differ, depending on whether the set's operation is normal or abnormal.

The theory of operation of the oscilloscope is not difficult to understand if you study it one circuit at a time and determine exactly what each circuit does. Do not become confused by the names of the various circuits. The sweep circuit, for instance, is merely a circuit that generates a sawtooth of voltage that causes the electron beam to sweep across the face of the cathode ray tube (CRT). The sweep circuit causes the beam of electrons to sweep the face of the CRT. The speed of the sweep is determined by the frequency of the sawtooth waveform.

Some aspects of the CRT and the sweep voltage will be discussed in detail in this chapter in order to simplify the explanation of exactly how a waveform is presented on the face of the tube. All circuits of the oscilloscope operate toward this end; so if the sweep voltage and scope presentation are understood, it becomes merely a matter of learning how individual circuits operate to understand the oscilloscope.

CATHODE-RAY TUBE

The CRT is the part of the oscilloscope which displays information. All other parts of the set serve to cause this information to be displayed. A thorough understanding of the CRT is essential before you can understand the operation of "O" scope.

The one and only purpose of the CRT is to produce an electron beam that will focus to a small dot on its luminescent face. The tube must be capable of making the beam move in any direction. If the beam is moved across the luminescent screen at a speed faster than the eye can follow, and if that movement occurs more than 16 times a second (approximately), then the eye will see what appears to be a straight line. This action will be more completely understood as you study the physical properties of the CRT. These will be discussed in connection with an explanation of the electron gun, the focusing and accelerating anodes, and the luminescent screen.

By referring to figure 7-7 you can see that the CRT is similar to any other vacuum tube. It has a filament to heat the cathode to cause it to emit electrons, a grid to control the number of electrons leaving the cathode, and a means of accelerating the electrons toward the screen. The filament, cathode, and grid form the electron gun.

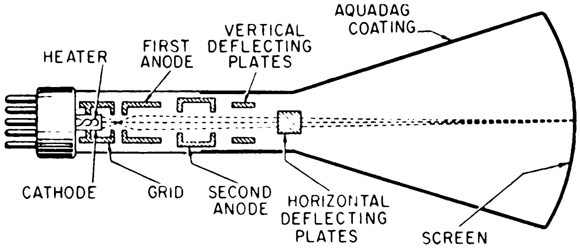


Figure 7-7.—Construction of CRT using electrostatic deflection and focusing.

The screen and aquadag coating within the tube envelope are comparable to the plate of the ordinary vacuum tube, with the exception that the screen luminesces, or lights up, when struck by electrons. The aquadag coating is a conducting paint inside the tube envelope that collects the electrons and returns them to the cathode.

The action of the CRT can be summed up in this manner: The electrons leave the cathode in a steady stream, the grid controls the amount or number of electrons emitted, the first anode (focusing anode) focuses the electrons in a beam that causes them to converge at the screen, the second anode (accelerating anode) accelerates the electrons to a high speed and helps to focus the beam, the vertical and horizontal deflection plates position the dot on the screen, the screen lights up where the beam of electrons strike it, and the aquadag coating collects the electrons after they bounce from the screen.

The operation of a CRT is covered quite thoroughly in *Basic Electronics*, NavPers 10087. Focusing and accelerating action are explained in detail. Since *Basic Electronics* is one of the required training courses for the AT rating, it is recommended that you study the oscilloscope section in that course.

In order to enable you to better understand the operation of an oscilloscope, a more detailed description than is contained in *Basic Electronics* will be given to some topics. The CRT screen and the deflection plates will be discussed.

CRT Screen

The face, or screen, of the CRT is coated with a material that will give off light when struck with electrons. The amount of light is determined by two things: (1) The number of electrons striking a spot in a given length of time, and (2) the speed with which the electrons strike the spot. In the CRT shown in figure 7-7 the grid is used to vary the amount of electrons in the stream and all electrons acquire the same acceleration. It follows that the spot will be brighter if more electrons strike the screen.

The luminescent coating on the screen has the property of giving off light for some length of time after the electron has struck it. This is called "afterglow." The length of afterglow is determined by the type of material used for the coating. As the electron beam moves across the screen it leaves a trail of afterglow behind it that persists for a very short time. This motion, if it occurs often enough, enables the eye to see what appears to be a trace. The length of time that the screen glows or fluoresces at the point where the electron beam strikes it is known as screen persistence.

The spot on the screen is of no value unless it can be made to move in a prescribed manner. Deflection plates are built into the tube to cause the spot to move.

Deflection Plates

There are two different methods of deflecting the beam of electrons in a CRT—electromagnetic and electrostatic. Electromagnetic deflection is performed by a coil of wire that is placed around the neck of the CRT. This is the method used in most television receivers. It is described in *Basic Electronics*.

When plates are used to deflect the electron beam it is called electrostatic deflection. Most oscilloscopes employ electrostatic deflection, and this is the only type that will be discussed in this chapter.

Refer to figure 7-8 when studying the material on electrostatic deflection. Plates Y and Y' are termed the vertical deflection plates, which means that they deflect the beam up and down. When the shortened term "vertical plates" is used, it refers to the vertical deflection plates. The vertical plates will always be the plates that deflect the electron beam vertically, (between A and B in the figure).

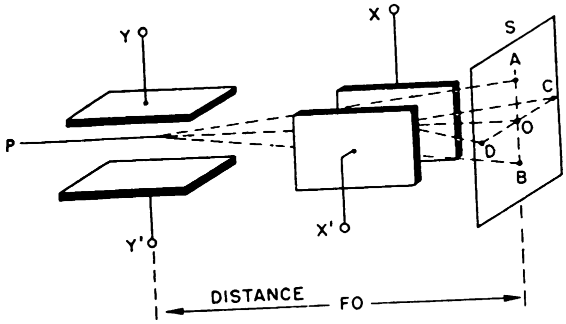


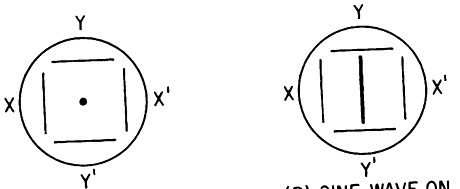
Figure 7-8.—Deflection plates for electrostatic deflection.

Plates X and X' are the horizontal deflection plates, and they deflect the beam between D and C on the screen. These plates are sometimes referred to simply as the "horizontal plates," but the term is understood to mean the horizontal deflection plates.

Both pairs of plates usually function simultaneously. Positioning of the beam is obtained by placing voltages on the plates. The negative electrons in the electron stream are attracted by a positive voltage and repelled by a negative voltage. Therefore, if a positive voltage is applied to plate Y and a negative voltage is applied to plate Y', the beam will be deflected upward toward A. The amount of deflection is determined by the amount of voltage applied.

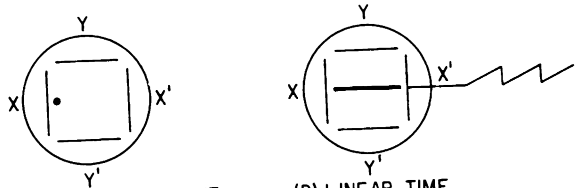
Voltages placed on the plates X and X' would deflect the beam in a similar manner, except horizontally.

Referring to figure 7-9, if all plates have equal voltage, the dot will be centered, as in A. If a sine wave is applied to the vertical deflection plates so that Y and Y' are alternately positive and negative, the dot will be deflected up and down. This will cause a vertical line to appear, as in B. If plate X has a positive voltage applied, the dot will move in that direction, as in C, and will remain there as long as the voltages are constant.



(A) ALL PLATES EQUAL VOLTAGE

(B) SINE WAVE ON VERTICAL PLATES



(C) X PLATE POSITIVE X' PLATE NEGATIVE

(D) LINEAR TIME BASE

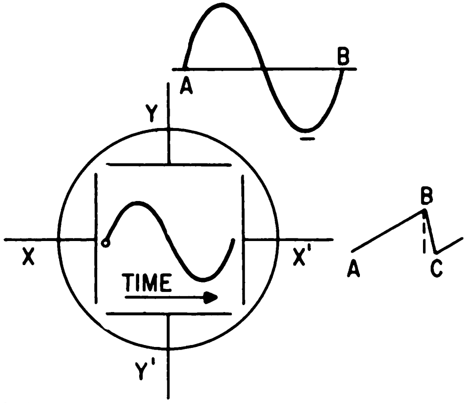
Figure 7-9.—Deflection of electron beam.

Suppose, however, the dot is to be moved from its position at C to the other side of the screen. This can be accomplished by applying a higher positive voltage to X' than is applied to X. As the voltage on X' becomes higher, the dot moves farther in that direction. An increase of one volt will move the dot a certain amount, and an increase of two volts will move the dot twice that amount. Thus it can be seen that the motion is linear. It only remains to determine what kind of voltage should be applied to X' to give a horizontal line, as in D.

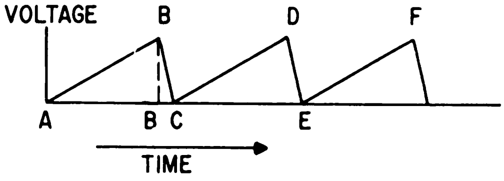
The answer: A sawtooth voltage. The sawtooth waveform seen in D can be generated by a sawtooth generator. This is called the sweep generator because it causes the dot to sweep from side to side. The sawtooth voltage rises linearly to the voltage necessary to pull the dot across the screen. After reaching this point it falls very quickly to the starting point, allowing the dot to return rapidly to its starting point, as in C. The sawtooth voltage immediately begins to rise again, pulling the dot toward X' again. Thus the dot sweeps from plate X to plate X' every time the sawtooth voltage rises on X'.

It has already been stated that the dot moves linearly across the screen because the sawtooth voltage increases at a linear rate. The line formed by this motion can be called a "linear time base" because it takes time for the dot to move across the screen. The amount of time is the length of the sawtooth voltage, and this is the base from which all deflection occurs. The sweep generator that generates the sawtooth voltage causes a linear time base to appear and is, therefore, called a linear time base generator.

Figure 7-10 illustrates how a sine wave is presented on the CRT. Initially the plates have the proper d-c voltages applied to position the dot near plate X. Now, two things happen at the same time: (1) The sawtooth is applied to plate X' which starts moving the dot in that direction, and (2) the sine wave is applied to plate Y which starts moving the dot in that direction. The electron beam (the dot) will move in any direction that the voltages on the plates direct. The sawtooth pulls the dot across the screen. The sine wave pulls the dot upward while it is positive and pushes it downward while it is negative. If the sine wave and the sawtooth are exactly the same length (A to B in fig. 7-10), then one cycle of the sine wave will appear on the screen.



(A) SINE WAVE PLOTTED AGAINST TIME



(B) SAWTOOTH WAVEFORM PLOTTED AGAINST TIME

Figure 7-10.—Sine wave presentation. (A) Sine wave plotted against time; (B) sawtooth waveform plotted against time.

Note in figure 7-10 (B) that the sawtooth voltage builds up from A to B and very rapidly decreases to C, but there is a time element between B and C. The voltage cannot decrease from maximum to minimum in zero time. During the fall time from B to C the beam is swept back very rapidly across the screen. It repositions near the X plate so that it will begin its travel again as the sawtooth increases its voltage from C to D. The time required for the dot to fly back across the screen (B to C on the sawtooth) is called "flyback time," and occurs so fast that it is not normally visible on the screen. This flyback trace can usually be seen if the scope brilliance is turned to its brightest position.

Sweep Time

Sweep time is the term used to denote the length of the sawtooth waveform, which is the time required for the beam to be swept across the screen. In figure 7-10 (A) the sweep time is the same as the time for one cycle of the sine wave, so only one cycle appears. If the sweep time was twice the length of the sine wave (A to B on the sawtooth was twice the time of A to B on the sine wave), then two sine wave cycles would appear.

TYPICAL OSCILLOSCOPE

Figure 7-11 shows the essential elements of any oscilloscope. As can be seen, it consists fundamentally of a sweep generator, horizontal and vertical amplifiers, and a cathode-ray tube. Note the switch at the horizontal signal input. For most applications the switch will be connected as shown, but

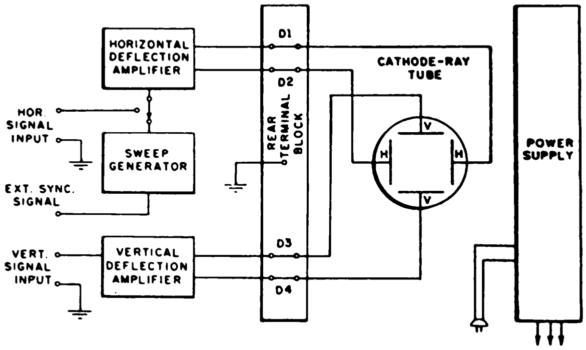


Figure 7-11.—Essential elements of an oscilloscope.

provision is made for placing a signal on the horizontal plates from an outside source rather than from the sweep generator.

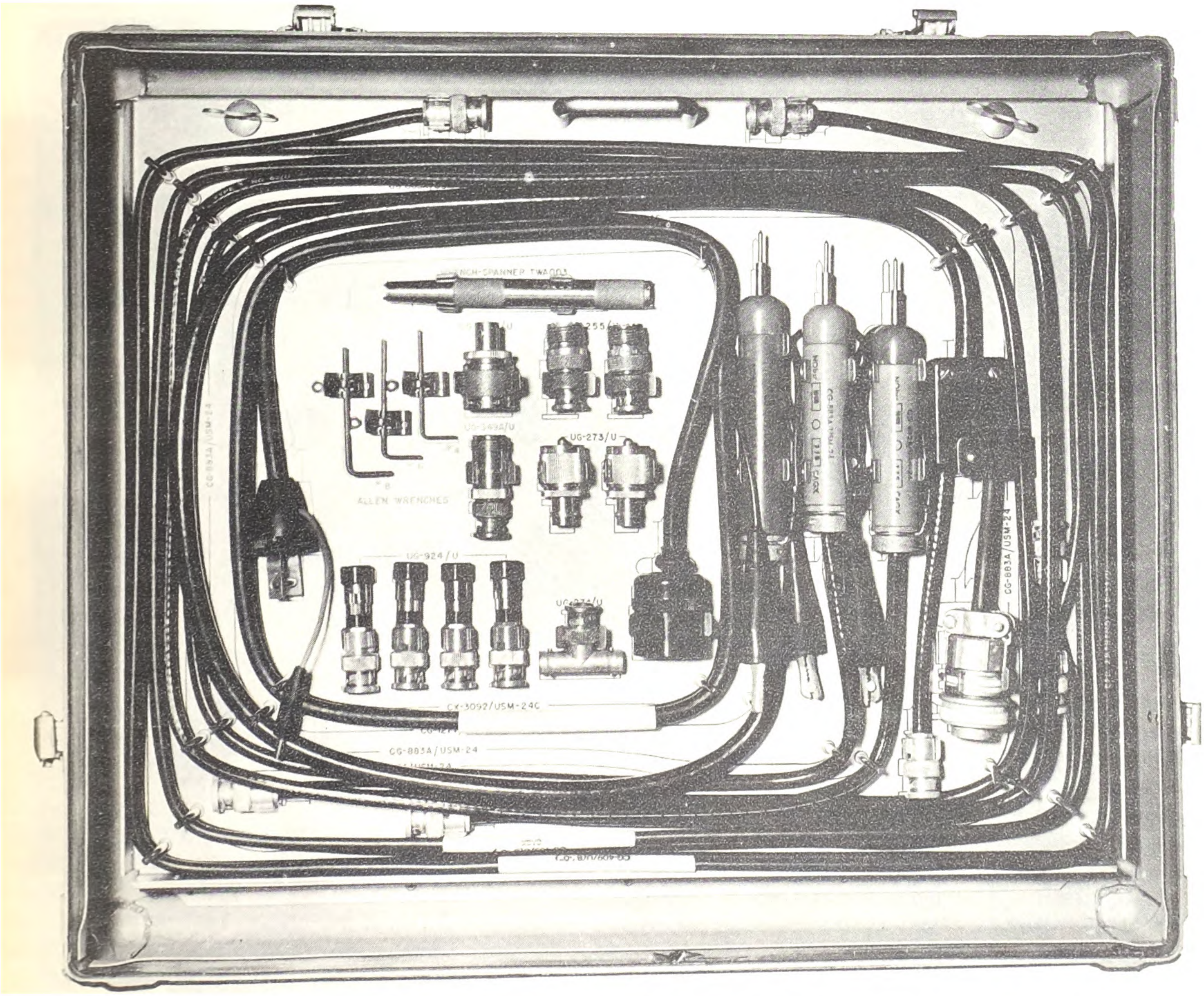
This very basic block diagram can be expanded to include all the refinements that are necessary for a workable, finished oscilloscope. An example of such an oscilloscope is the USM-24. The USM-24 is representative of oscilloscopes that you will use.

USM-24 Oscilloscope

This oscilloscope is portable and is intended primarily for bench testing electronic equipment. It may be used to measure the amplitude, shape, and time duration of waveforms. The complete equipment is shown in figure 7-12.

The linear time base, as already described, permits observation and measurement of signals against time. The sweep duration is controlled by two potentiometers. One is called Sweep μS and the other Fine Sweep. The sweep may be varied from 1.25 μsec. to 125,000 μsec. Also, any one-tenth of the observed signal may be selected and expanded for closer observation. The linear time base can be operated either in a trigger or a periodic fashion.

Signal amplification is uniform over a wide frequency band so that flat-topped pulses may be adequately displayed. The signal to be



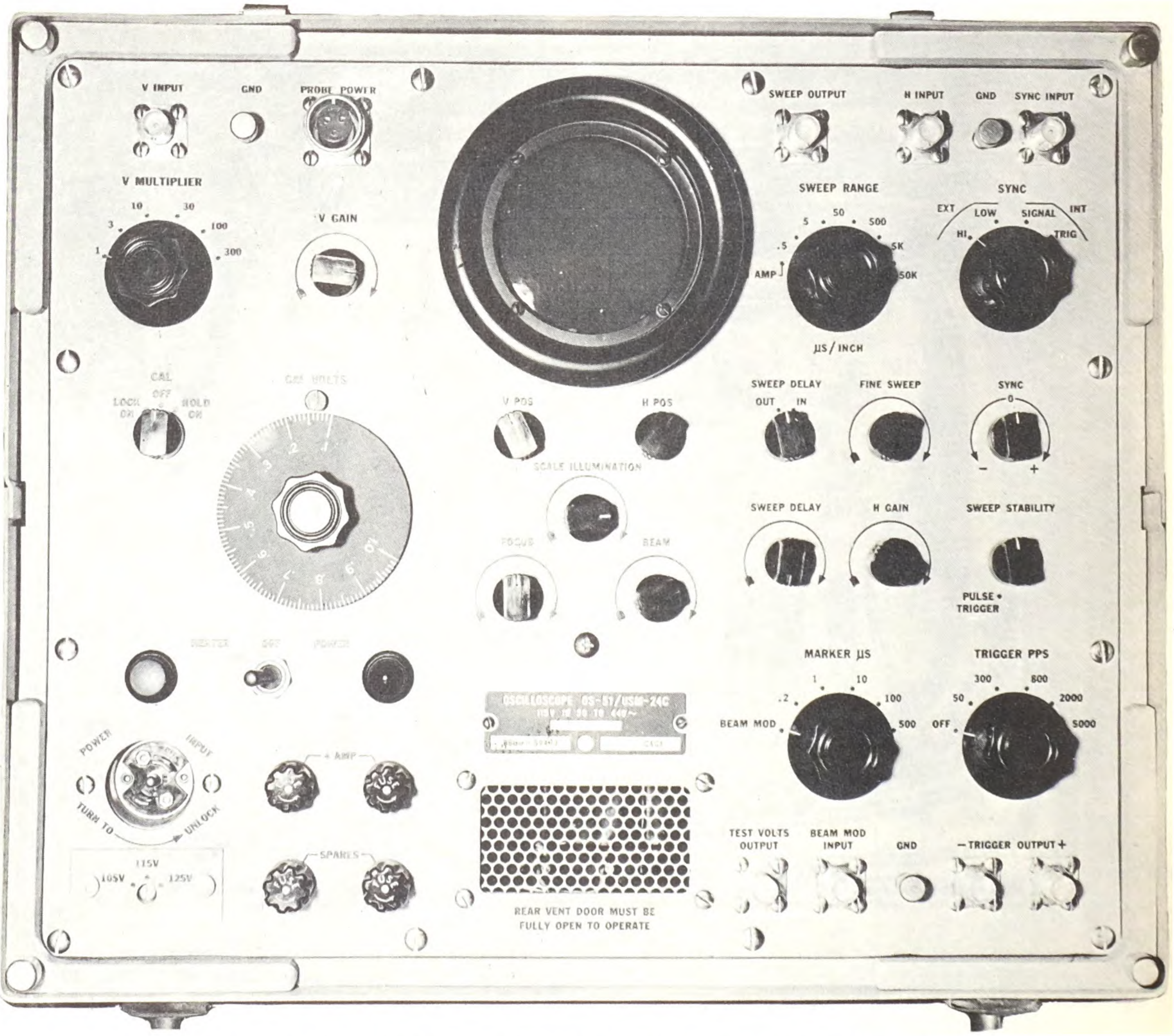
(A) OSCILLOSCOPE COVER CW268/USM-24

Figure 7-12.—Oscilloscope USM-24.

observed is applied to the vertical input. This input's sensitivity is such that signals with peak value from 0.01 to 150 volts may be observed directly. Two types of test probes are provided. One enables signals up to 600 volts to be observed; the other enables signals up to 2 volts to be observed with only 9 $\mu\mu$f. shunt capacity loading. The vertical channel includes a delay line of 0.055 μsec., thus making it possible to observe the leading edge of a pulse that triggers the linear time base.

It should be remembered that the linear time base forms all the signals observed on the scope. Therefore any signal that is applied to the vertical input merely distorts the time base to resemble that signal. A marker generator is incorporated in the set; this generator produces bright spots on the time base. These spots may be spaced from 0.2 μsec. to 500 μsec. apart. Spacing is controlled by the marker μsec. switch.

The frequency of an applied signal (signal from the set under test) may be determined by using the microsecond markers. When the duration of one cycle is determined, frequency may be computed by the formula $F = 1/T$; where F is frequency in cycles per second, and T is time in seconds. For example, if it is determined that one cycle of a waveform is 500 μsec. long, then its frequency is



(B) OSCILLOSCOPE OS-26/USM-24

Figure 7-12.—Oscilloscope USM-24—Continued.

$$F = \frac{1}{500 \times 10^{-6}} = 0.002 \times 10^{6} = 2{,}000 \text{ c.p.s.}$$

The USM-24 has provisions for measuring the amplitude of a signal by comparing it with the known amplitude of an internally-generated signal. This is a rather simple operation which you will learn quickly when the occasion presents itself.

Figure 7-13 is a block diagram of the USM-24 oscilloscope. This diagram is a slightly simplified version of the one in the instruction book for the USM-24. By becoming familiar with the diagram in figure 7-13 you should be able to better understand the operation of the set should an occasion arise when you need to make reference to the equipment's instruction book.

The publication NavShips AN16-30 USM-24-3 explains the oscilloscope in detail. Also, the Navy Training Course, *Basic Electronics*, NavPers 10087, contains an explanation of the circuits represented by the block diagram of figure 7-13 of this chapter.

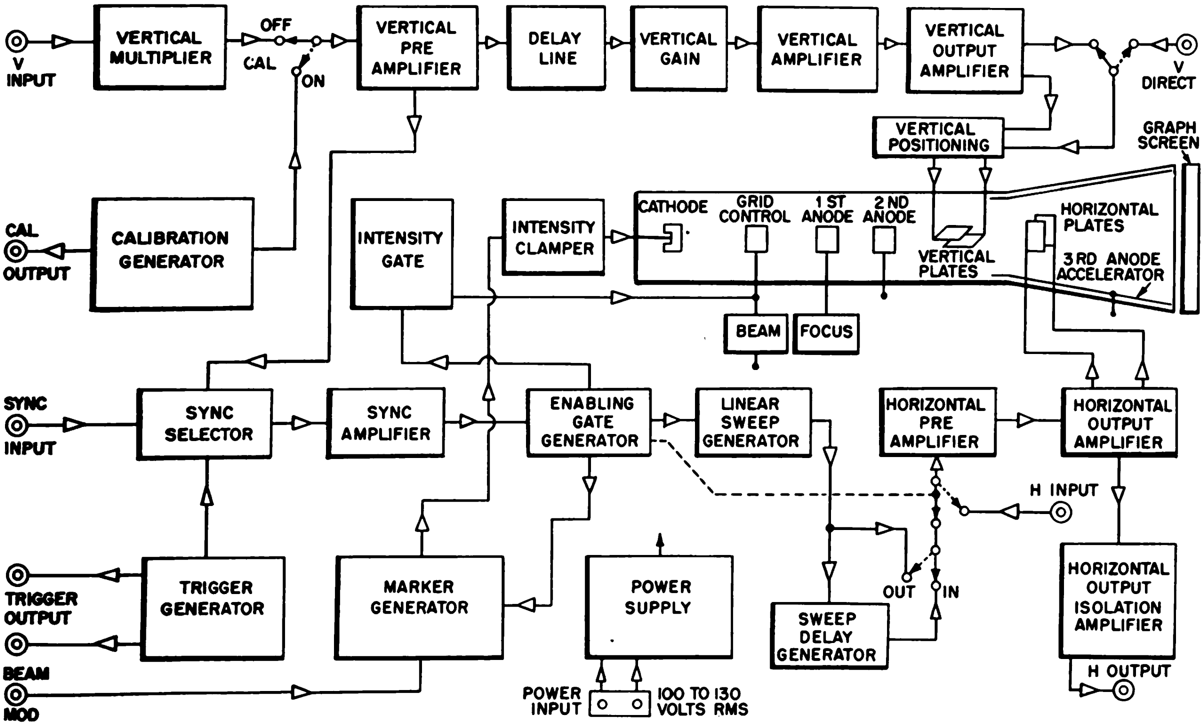


Figure 7-13.—Block diagram of oscilloscope.

RF Wattmeter

A **wattmeter** is used to indicate the power output of a transmitter. More exactly, it indicates the power applied to the input of the wattmeter. It may also be used as a dummy load to prevent radiation of energy into space when radiation is undesirable, usually during transmitter tuning.

Several types of wattmeters are in use in the field. All operate on the principle of power absorption. Most wattmeters are built for use within certain frequency limits, and are designed with a maximum power absorption capability.

Heat is generated in a wattmeter when it absorbs power from a transmitter. This heat must be removed. The usual method is to build the meter with cooling fins. These fins surround the meter and the heat is dissipated into free air. This is explained more fully later.

For accurate indication of transmitter power output it is necessary that the wattmeter absorb as much of the power as possible. This requires that the meter input impedance match the transmitter output impedance; that is the condition under which maximum transfer of power is obtained.

A general understanding of the theory of operation of wattmeters should prove helpful to the technician. A meter that is typical of those that you will operate and maintain is the RF Wattmeter Model 670.

MODEL 670 WATTMETER

The Model 670 is a portable absorption type RF wattmeter used to measure RF power from any source. It is also used to facilitate the tuning of transmitters. It functions without radiating signals into space. The Model 670 does not require any accessory equipment and operates without the use of an outside power source.

It is designed for use only with 50-ohm coaxial circuits, for which it serves as an almost reflectionless termination. Continuous wave (CW), amplitude modulated (AM), and frequency modulated (FM) signals may be fed to the unit. It is not intended for use with pulsed power signals such as those obtained from radar transmitters.

The maximum power input of the wattmeter in ordinary air is 500 watts (on a direct reading scale). Its frequency range is from 30 to 500 megacycles with accuracy of ±5 percent of full scale value.

The wattmeter may be used as a dummy antenna. When used in this way, only the load resistor is utilized, the feed line from the transmitter must be 50-ohm coaxial cable, and the input cannot exceed the power limitations of the unit.

Summary of Technical Characteristics

Load power	Up to 500 watts continuous in free circulating air.
Measurement range	0 to 500 watts in three ranges; 0-25, 0-100, 0-500.
Frequency range:	
For power measurement	30 to 500 megacycles.
As dummy antenna	0 to 3,000 megacycles.
Circuit	Coaxial, 50-ohm impedance.
Modulation types	CW, AM, or FM. Not for use with pulsed power.
Accuracy	±5% of full scale.

Equipment

The equipment (fig. 7-14) consists of two major units—the load resistor unit (A), and the microammeter (B). Both units are fitted with rubber bumper feet and carrying handles are provided on the top of each unit. The units are self-contained and may be carried individually. The load resistor unit includes the line termination, heat dissipator (coolant tank and radiator), and an RF voltage detector. RF input is through either an LC or N-type interchangeable coaxial connector on the nosepiece. The spare connector is attached to the back of the heat radiator. The microammeter is fed from the output of the RF voltage detector by a shielded cable. It reads measured power directly in RF watts on the selected level of the three-range scale.

Principle of Power Measurement

The wattmeter measures the power dissipated in the resistor by the expression $W = E^2/R$. Here E is the voltage across the resistor R, through which the RF energy is flowing, as shown in figure 7-15. It is important in this measurement that the resistance of R be equal to the output impedance of the transmitter (50 ohms) and that the voltmeter be accurate at, or corrected for, the operating frequency. The construction of the load resistor produces a nearly constant characteristic impedance over the frequency range from 0 to 3,000 mc., well beyond the 30 to 500 mc. measuring band.

Figure 7-16 is a simplified schematic of the wattmeter. Capacitors *C*302 and *C*305, with resistor *R*302, form an RF voltage divider across the load resistor *R*301. Capacitor *C*302 is of small value, to permit minimum effect on *R*301. The rectifying action of the crystal diode *CR*301 permits *C*305 to be charged, by alternate half-cycles, to the peak of the RF voltage applied across it by the voltage-divider action. Resistor *R*305 and microammeter *M*301 form a d-c voltmeter circuit that measures the d-c voltage developed across *C*305. Capacitor *C*301 is an RF bypass for meter *M*301. This arrangement makes up a shunt-diode voltmeter circuit. The circuit components, except the meter, are built onto the input of the RF load resistor.

Figure 7-17 is a cutaway diagram of the wattmeter. In this figure capacitors *C*301 and

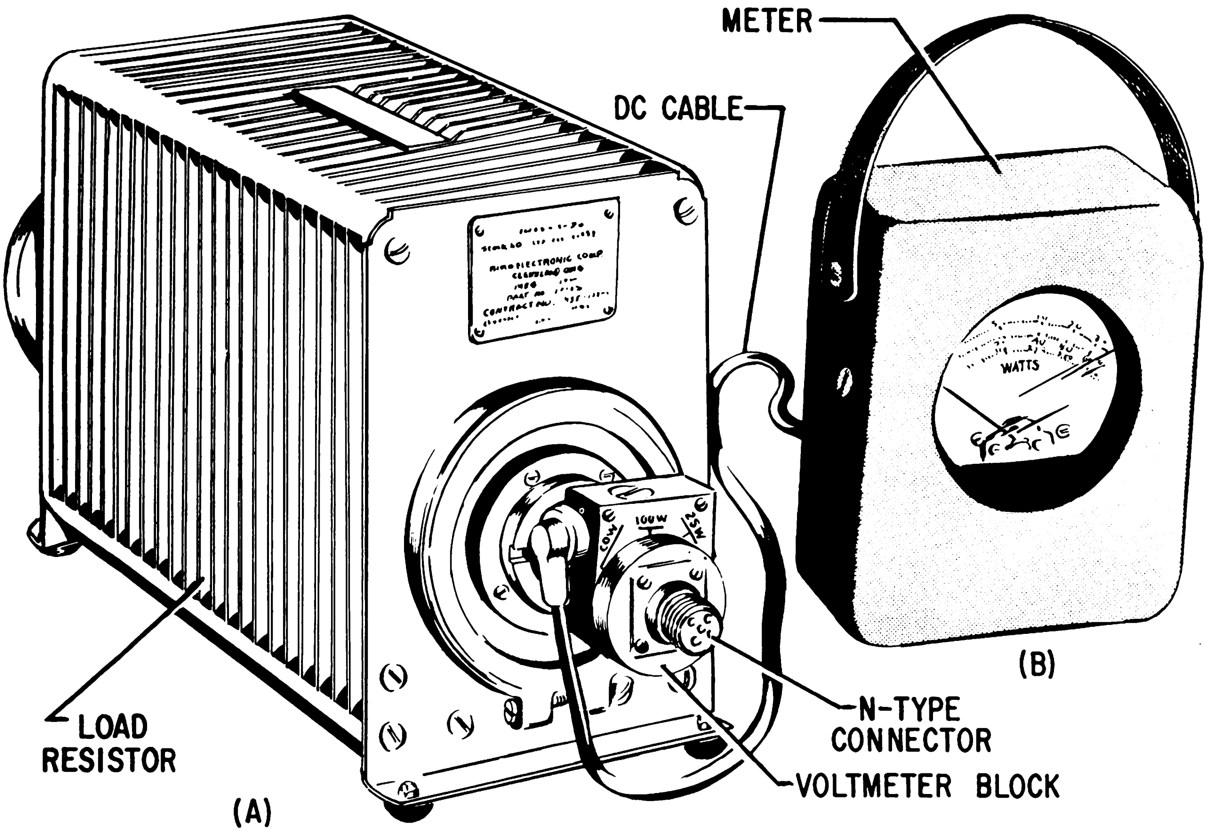


Figure 7-14.—Model 670 RF wattmeter. (A) Load,resistor unit; (B) meter.

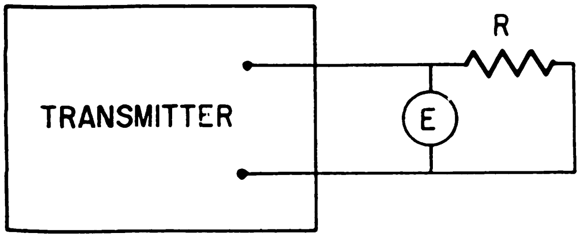


Figure 7-15.—Basic method of power measurement.

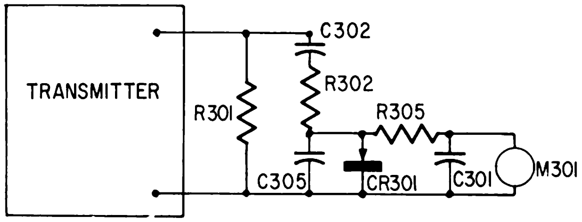


Figure 7-16.—Simplified schematic diagram.

C305 appear to be connected in series rather han in parallel as shown in figure 7-16. This s not true, however. These capacitors are of he button-mica type, as illustrated in figure 7-18. In this type capacitor a conductor passes irectly through the inner plate, which is surounded by the mica dielectric. The outer late is soldered directly to the chassis, so hat capacitance exists between the conductor nd chassis. Consequently, the use of a buttonica capacitor has the same effect as conecting a capacitor of the ordinary type between he conductor and ground.

Three-Range Voltmeter Circuit

The wattmeter measures three separate power ranges, 0-25, 0-100, and 0-500 watts respectively. These ranges are selected by rotating the voltmeter block. The rotation changes the capacitance of the series capacitor in the RF voltage-divider circuit (C302 in fig. 7-16). This avoids overloading the crystal diode on the higher power ranges. If you are uncertain about the amount of power from the transmitter, always start measuring with the meter set to the highest range.

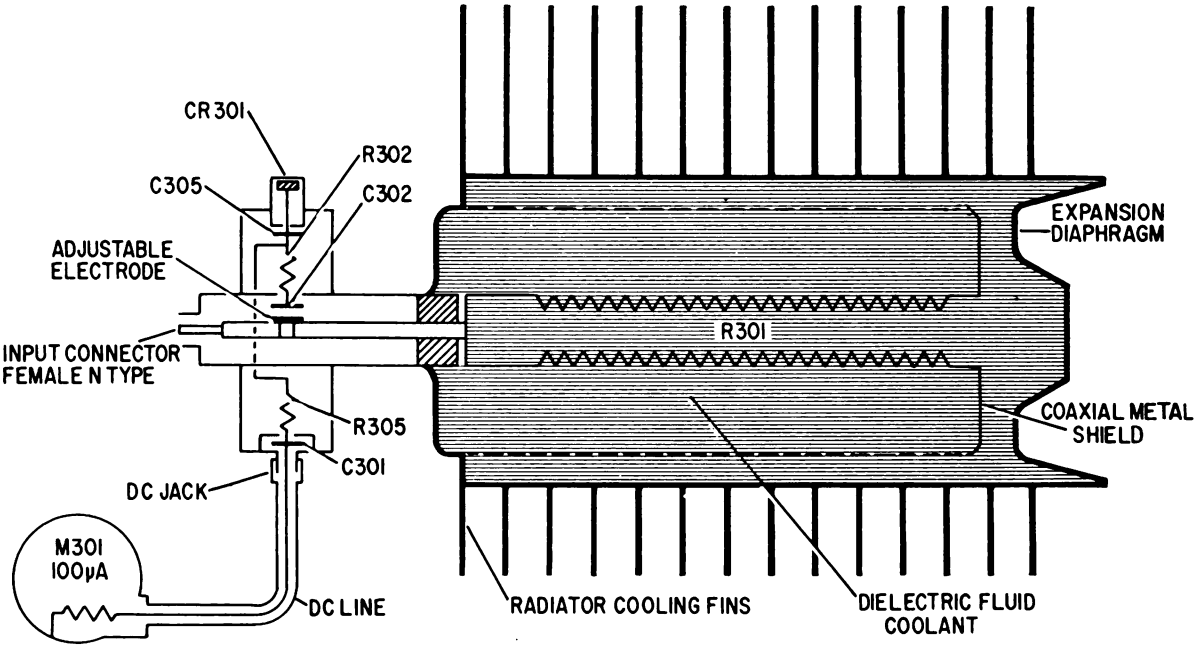


Figure 7-17.—Cutaway diagram of wattmeter.

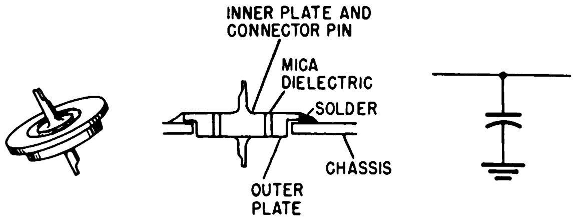


Figure 7-18.—Button-mica capacitor.

RF Load Resistor

The structure of load resistor *R*301 (fig. 7-17) is coaxial. It has a characteristic impedance of 50 ohms from the input connector to a point about 2 inches behind the large mounting flange. The load resistance proper begins close to this point. The power dissipating portion of the resistor is the external surface of the cylindrical, carbon film-on-ceramic resistor, which forms the center conductor of the coaxial termination system. This film is connected to a metal shell at one end of the resistor. This forms the return, or outer conductor, of the coaxial structure.

Cooling System

Resistor *R*301 is immersed in oil. This oil conducts the heat that is generated by the RF energy to the inside wall of the cylinder. From there, the heat is conducted to the radiator cooling fins and, by convection, is carrie away by the surrounding air.

Because the oil, which is a dielectric, form part of the coaxial structure, a significant los of oil will change the RF input impedance o the dummy load. If the oil loss is above on percent of the net volume, the measurement may be noticeably affected. Oil capacity i one gallon.

An expansion diaphragm is provided at th rear of the resistor housing (fig. 7-17). A the temperature of the oil rises, the oil expands; the diaphragm allows for this expansio

Crystal Diode

A 1N79 crystal diode, *CR*301, is inserte into a holder on the side of the voltmeter bloc and covered by a screw cap. This diode maintains a d-c voltage across the button-mic shunt capacitor *C*305. The diode is locate close to the tip of the crystal connector (fi 7-17). A small cylinder of ferrite surroun this connector and serves as an RF cho against excessive energy at high frequencie The components are arranged in the voltmete block for effective RF bypassing, with a minimum of residual inductance.

Voltmeter Adjustment

The capacitors shown in figure 7-19 as *C*302, *C*303, and *C*304 are actually three electrode stubs (one for each meter range) mounted on the center conductor of the load resistor unit. A single electrode is mounted on the movable voltmeter block. This single electrode is placed opposite one of the three respective fixed electrodes when the voltmeter block is set at one of the three power-range positions. At the time of manufacture, each fixed electrode is specifically adjusted to calibrate its particular power value with the assigned crystal. Individual calibration of each wattmeter is necessary because of the lack of uniformity between crystal diodes. After the wattmeter is calibrated for one crystal diode, a second crystal diode (supplied as a spare) is selected to match the characteristics of the first. The voltmeter block is sealed after calibration and cannot be adjusted by field maintenance procedures. If a diode other than the type supplied with the wattmeter is used, an error up to ±20 percent of full-scale power reading may be experienced.

D-C Output

The output of crystal rectifier *CR*301 is fed to the d-c meter circuit through calibrating resistor *R*305 (fig. 7-19). Bypass capacitor *C*301 is a button-mica type, mounted inside the d-c connector jack. The voltmeter block, the d-c cable, and all other components of the meter circuit are protected by grounded shielding when the dummy load is grounded. This shielding and the bypass capacitor *C*301 keep stray RF fields from affecting power indications on the meter.

Measuring Transmitter Power

With the transmitter turned off, connect the transmitter output to the dummy load. Use no more than 5 feet of coaxial cable, and use only 50-ohm cables and fittings. Even with a transmitter having a 75-ohm output, use a 50-ohm cable back to the output jack of the transmitter. Set the voltmeter block to select the desired range. Caution: If the approximate power output of the transmitter is not known, set the voltmeter block to the 500W position. Turn on the transmitter and determine the correct power range of the wattmeter. If the voltmeter block is set below the input power, the crystal diode and meter may be damaged.

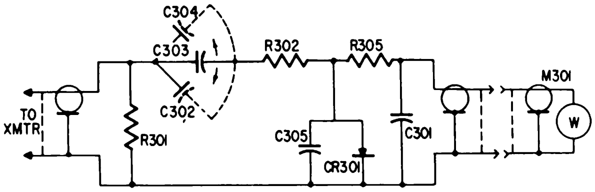


Figure 7-19.—Overall schematic of wattmeter.

Allow a few minutes for the transmitter to warm up and stabilize itself. The wattmeter indicates the power that is applied at the input connector of the dummy antenna. Losses introduced by the cable between the transmitter and the dummy load, if significant, must be added to the power indicated by the meter. Consult the HSI for the particular transmitter that you are checking to determine what its power output should be.

Using As Dummy Antenna

When used without the crystal diode and the meter, the dummy load will serve as a 50-ohm termination for transmitters at all frequencies from 0 to 3,000 mc.

To remove the crystal, unscrew the crystal cap on the right of the voltmeter block. Insert the edge of a knife under the flange of the crystal diode and pry it away from the flat springs that hold the diode. Remove the diode with the fingers. Do not remove when RF power is on, as the crystal may be damaged.

Disconnect the meter by unscrewing the meter cable connector at the d-c jack on the voltmeter block. This jack is opposite the crystal socket.

Operate the dummy load within the same power limits as when measuring transmitter power.

Standing Wave Ratio Meter

Oftentimes it is desirable to determine how much of the generated RF power is actually radiated from the antenna, or more specifically, to check the coaxial transmission line for losses. This test is made by using a standing wave ratio meter. There are different types of meters. All are similar in that they indicate the amount of power produced by the transmitter as compared to the amount of power reflected from the antenna back to the transmitter. The MM-706 is a typical standing wave ratio meter.

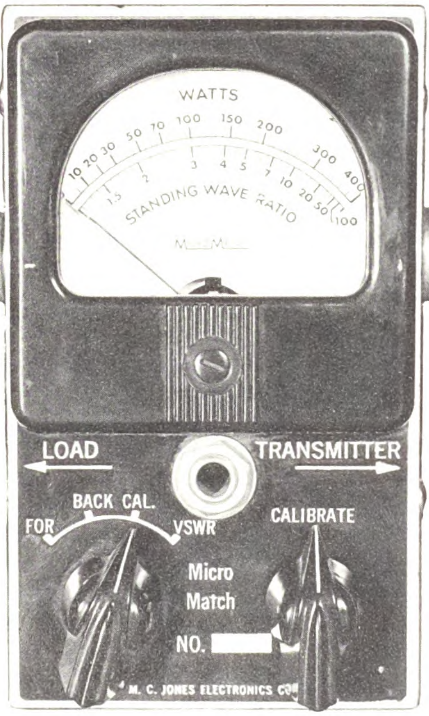


Figure 7-20.—MicroMatch MM-706.

MICROMATCH MM-706

This is a small portable instrument that may be employed to read directly (1) the RF power output of a transmitter, (2) incident power, reflected power, and net power delivered to a load, and (3) the voltage standing wave ratio (VSWR) of the associated transmission line. It also provides a means of monitoring the modulation on an AM carrier.

This instrument may also be used as an absorption type wattmeter by employing an appropriate dummy load resistor adapter supplied for that purpose.

The MicroMatch may be installed permanently in a transmitting system to provide continuous indications, or it may be used only during tuning and test procedures. The output of the transmitter under test is attached to one end of the coupler unit, and the load, or antenna, is connected to the other end. (See fig. 7-21.)

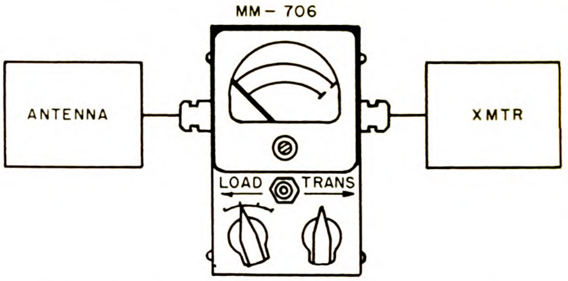


Figure 7-21.—Block diagram, typical application.

The coupler unit has no effect on the operation of the transmitter or the load. A sampl of the RF energy passing through the couple is applied to the indication circuit of the instrument. The RF energy is rectified by series crystal unit and applied to the indicato meter.

The particular function of the instrument i selected by means of a switch on the fron panel. If remote indication is desired (a remote meter, or headphones), the lead to th remote indicator is connected through the jac on the front panel. When a remote indicato is used, the circuit to the local meter i opened.

Functional Operation

Figure 7-22 is a schematic diagram of th meter. Coupler *Z*2 is connected in the line between the transmitter and the antenna. R power passes through this unit. This power i sampled by means of pickoff in *Z*2 and couple through the crystal unit *CR*2 to *P*2. The properties of *CR*2 are such that in the direction ind cated by the arrow head in figure 7-22 the r sistance is low, whereas in the opposi direction the resistance is very high and co duction is practically negligible.

When *S*1 is in the FOR position, the san pled RF power is rectified by *CR*2 and appli through the two sections of the switch, resist *R*2, and the normally closed contacts of *J*1 the meter.

Filtering of the rectified voltage is obtain by means of a capacitor built into the c which secures the crystal units in the plug

When *S*1 is placed in the BACK positi the sampled RF power is taken from the lo end of coupler *Z*2. Rectification occurs the same manner as previously explained a meter *M*1 reads the reflected power.

The standing wave ratio of a transmiss line is the ratio of the maximum RF power

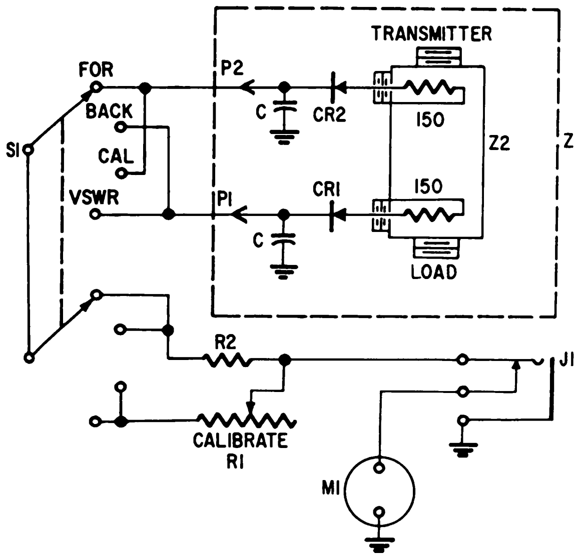


Figure 7-22.—Schematic diagram of meter.

minimum RF power. With *S1* in the CAL position, the meter is reading forward power or, almost directly, the power output of the transmitter. The circuit to the meter bypasses the fixed resistor *R2* and includes the potentiometer *R1*. This potentiometer is adjusted to produce full-scale deflection of the meter. This is the maximum power. Placing the selector switch in the VSWR position causes the RF power at the load end of the coupler unit to be sampled. At this point the reflected power from the antenna back toward the transmitter is bucking the forward power. Therefore, the load end is a low power point. Since the meter was set for full-scale deflection at the maximum power point, the reading obtained from the low power point is a direct indication of the voltage standing wave ratio.

Controls

There are two controls on the instrument. They are the selector switch *S1* and the CALIBRATE potentiometer *R1*. The potentiometer is used to set the full-scale deflection of the meter before taking standing wave ratio readings. The transmitter must supply at least 15 percent of the rated power of the instrument, in this case 60 watts, to produce full-scale reading. If less than 15 percent of the rated power is available, a formula must be used to determine VSWR. This is explained in the HOI for the instrument.

Selector *S1* is a two-pole, four-position rotary switch. Its four positions and their uses are:

1. FOR (forward or incident power)—In this position the meter reads the RF power traveling to the antenna.

2. BACK (backward or reflected power)—In this position the meter reads the power reflected from the antenna back toward the transmitter.

3. CAL (calibrate)—This position is used when calibrating the meter before reading standing wave ratio.

4. VSWR (voltage standing wave ratio)—In this position the meter reads the standing wave ratio of the transmission line.

After the instrument has been properly installed in the transmission line, as close as practicable to the transmitter, operation is a matter of setting the selector switch for the proper reading and interpreting the dial reading.

Power Readings

Set CALIBRATE control to its maximum CCW position. Set the selector switch to FOR. The meter will read forward power. Turn on the transmitter and bring the power up gradually, if possible. If the transmitter is equipped with TUNE and OPERATE positions of the high voltage, it is advisable to place it in the TUNE position first, and then advance it to the OPERATE position. Read the power output of the transmitter directly on the upper scale labeled WATTS.

Set the selector switch to BACK. The meter reading on the WATTS scale will now represent the actual reflected or backward power. The net power traveling toward the antenna or load is equal to the difference between these two readings.

The special MicroMatch circuit employed in this instrument tends to make the RF power readings independent of frequency in the middle frequency region. However, at frequencies near the low or near the high frequency limit of the instrument, the reading of the meter must be corrected. The correction factor should be taken from the frequency correction chart for RF power readings given in the HOI for the specific instrument in use.

VSWR Readings

Turn the selector switch to CAL. Adjust the CALIBRATE control until the meter reads just full scale.

Turn the selector switch to VSWR and read the voltage standing wave ratio on the lower scale of the meter.

Modulation Monitor

This MicroMatch unit can be employed to monitor the modulation of an AM carrier. The monitor output is taken from jack *J*1 on the front panel of the instrument and can be applied to a pair of headphones, or an a-c voltmeter. The signal obtained at the jack is a duplicate of the modulation applied to the carrier.

The HOI and HSI for the MicroMatch give the adjustments and checks necessary for proper operation of the instrument. Probably the only trouble to be encountered will be crystal changes, and there are only two requirements to be met to perform this operation. First, choose a replacement crystal that indicates the correct power of a known source (explained fully in the HOI); and second, be sure to replace the proper cap on the crystal. Switching the crystal caps will result in improper selector switch positioning.

Field Strength Meters

In measuring the performance of antenna systems, the important quantities to be found are the radiated power, the directions in which the power is radiated, and the strength of the radiated wave. The radiated power can be measured in several ways, the simplest being based on the measurement of the antenna current and the antenna radiation resistance. The directions of maximum radiation and the strength of the radiated wave are found by field strength measurements.

The field strength of radio waves is measured in terms of the voltage induced by the wave in a receiving antenna. The unit of field strength is the volt-per-meter, but since the actual values of induced voltage are quite small, the microvolt-per-meter is a more convenient unit in practical applications.

In absolute field strength measurements, the exact amount of voltage induced in the receiving antenna must be found, and the field strength is then derived from this value by application of an appropriate mathematical formula based on the type of receiving antenna employed. (Loops are generally used in low-frequency measurements.) The equipment used in absolute field strength measurements is rather complex and bulky, and since it is often unnecessary to know the exact amount of voltage present in the wave, much simpler measuring devices are often used. These measure relative field strength instead of absolute field strength. Relative field strength measurement is a comparison of the strength of one radio wave with that of another or with an arbitrarily selected standard.

Relative field strength measurements are of importance when an antenna is being tuned, oriented, or modified in any way. The usual procedure in such operations is to place the relative field strength meter at a considerable distance (not less than several wavelengths) from the antenna being measured. Readings are taken before the antenna is adjusted or the equipment modified. After adjustment, the field strength readings are taken again and compared with the previous values to determine the effect of the changes on the radiated signal strength.

Most relative field strength meters are either of the crystal rectifier type or the vacuum tube voltmeter type. Each of these employs one or more tuned circuits, a pickup antenna, some type of rectifier, and a current indicator. The pickup antenna is placed in the radiated field and the tuned circuit set in resonance at the frequency of the signal to be tested. The voltage induced in the tuned circuit is rectified either by a crystal rectifie or by a vacuum tube. In the crystal type, the rectified current is usually applied directly to the current meter, and the deflection of the meter is an indication of the strength of the signal. In the vacuum tube voltmeter type o field strength meter, the voltage developed i the rectifier is applied to the grid of an amplifier. The grid voltage results in a deflection of the current meter which is placed in th plate circuit of the amplifier.

In (A) of figure 7-23 a simple type of crystal detector field strength meter is shown The crystal detector is mounted in the cente

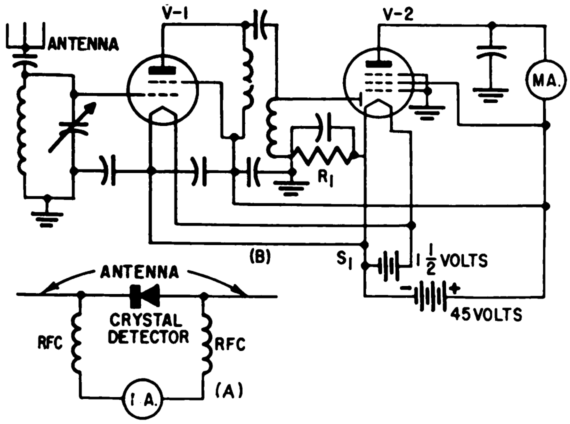


Figure 7-23.—(A) Crystal field strength meter; (B) vacuum tube field strength meter.

of a pickup antenna, whose length ideally is one-half wave at the frequency of the received signal. The crystal is coupled to a 0-1 milliammeter through radiofrequency choke coils. The induced signal is rectified by the crystal and the resulting current is indicated on the milliammeter. This type of meter is used at distances of four or five wavelengths from the transmitting antenna and for low-power transmitter measurements.

In (B) of figure 7-23 a considerably more sensitive field strength meter is shown. The tube *V*1 is an RF amplifier, the output of which is impedance coupled to the diode section of *V*2, a detector-amplifier. The rectified signal voltage is developed across *R*1, one end of which is attached to the filament-cathode of the amplifier tube. The voltage developed across *R*1 controls the plate current of *V*2 which is read on the milliammeter in the plate lead. The amount of change in the plate current is an indication of the strength of the signal induced in the pickup antenna of the field strength meter.

The tube *V*2 is a variable-mu pentode. In this type of amplifier, large signal voltages are amplified by a relatively small amount and small signal voltages receive much greater amplification. The *Eg-Ip* curve of such a tube is essentially a logarithmic curve. As a result of this fact, the meter in vacuum tube field strength circuits of this type can be calibrated directly in decibels, a logarithmic unit of power or voltage level.

When using field strength meters, errors and erratic readings can be caused by the presence of objects or persons near either the radiating source or the test meter, resulting in shadows and reflections in the radiated field.

The antenna of the test meter should always be extended to its full length so as to keep its effect on the tuning circuit constant.

Many types of field strength indicators are intended for use within 25 feet of the equipment being tested when antenna adjustments are made to achieve maximum radiation. The distance which results in the most satisfactory operation of the instrument for this test varies with the type of equipment being tested. Usually it is desirable to select a distance for the measurements which give a meter reading at about half-scale.

Frequency Meters

This discussion of frequency meters supplements the section entitled "Frequency Standards" found in chapter 13 of *Basic Electronics*, NavPers 10087.

A frequency meter is an instrument which is used to provide a simple, reliable and accurate means for adjusting the emitted or resonant frequency of transmitters, field strength meters, receivers, and other tuned detectors or emitters to a desired value. The term frequency meter is sometimes applied to test instruments which measure the frequencies of external signals and have no provision for emitting a signal. This latter type of instrument is more properly called a wavemeter.

Thus, a frequency meter can be used as a signal generator which supplies a moderate and extremely accurate signal for the adjustment of receivers and other types of detectors to a desired frequency within its designed range; and as a wavemeter for determination and adjustment to frequency of transmitters and other types of emitters.

The heterodyne type of frequency meter which contains a reference crystal for more accurate calibration is fairly typical. Heterodyne is a term that means two frequencies are mixed, or beat together, to obtain a third or difference frequency. This type of instrument usually consists of a heterodyne oscillator, an RF harmonic amplifier, a crystal-controlled oscillator, a mixer or detector, a modulator, an AF output amplifier, and a means for indicating frequency. Most frequency meters are furnished with a set of calibration charts giving the dial readings for the frequencies listed, together with a table of the crystal harmonics; thus, a complete and accurate frequency coverage over the designed range is provided.

In figure 7-24 is illustrated the block diagram of a typical heterodyne frequency meter.

In operation, the output of the variable frequency heterodyne oscillator is coupled into the RF harmonic amplifier. When signals are being generated for receiver testing purposes, the output of this harmonic amplifier is coupled to the antenna and the RF coaxial coupling connector. When the signals are being received as in transmitter testing, the harmonic amplifier output is coupled to the mixer (detector) tube along with the incoming signal under test.

The crystal-controlled oscillator operates at a fixed frequency, but is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies (check points) for adjusting the heterodyne oscillator, thus insuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its fundamental frequency. When it is desired to make this frequency check, comparison can be made to the standard WWV transmissions broadcast by the Bureau of Standards.

When the mixer is switched to the CALIBRATE ON position, the antenna and coaxial connector (RF input) are disconnected. The heterodyne oscillator output is combined with the output of the crystal oscillator in the mixer. This permits the calibration, or correction, by the zero beat method of the variable oscillator on the desired frequency. Zero beat is a condition that exists when two signals of the same frequency are beat together. The difference frequency is zero, and no tone is heard in the headphone. When the calibration switch is turned to the OFF position, signals from the antenna are coupled into the mixer along with signals from the heterodyne oscillator. The zero beat method is then used for the adjustment of the external transmitter under test.

With most frequency meters the audio amplifier has two functions. It amplifies the beat note produced by the mixing of the unknown signal and the calibrated heterodyne oscillator (modulation OFF), and thus gives a zero beat in the earphones when the signal of the equipment under test is adjusted to the frequency of the heterodyne oscillator. With the modulation switch in the ON position the stage serves as an audiofrequency modulator supplying an AF signal and modulating the RF signal produced by the heterodyne oscillator.

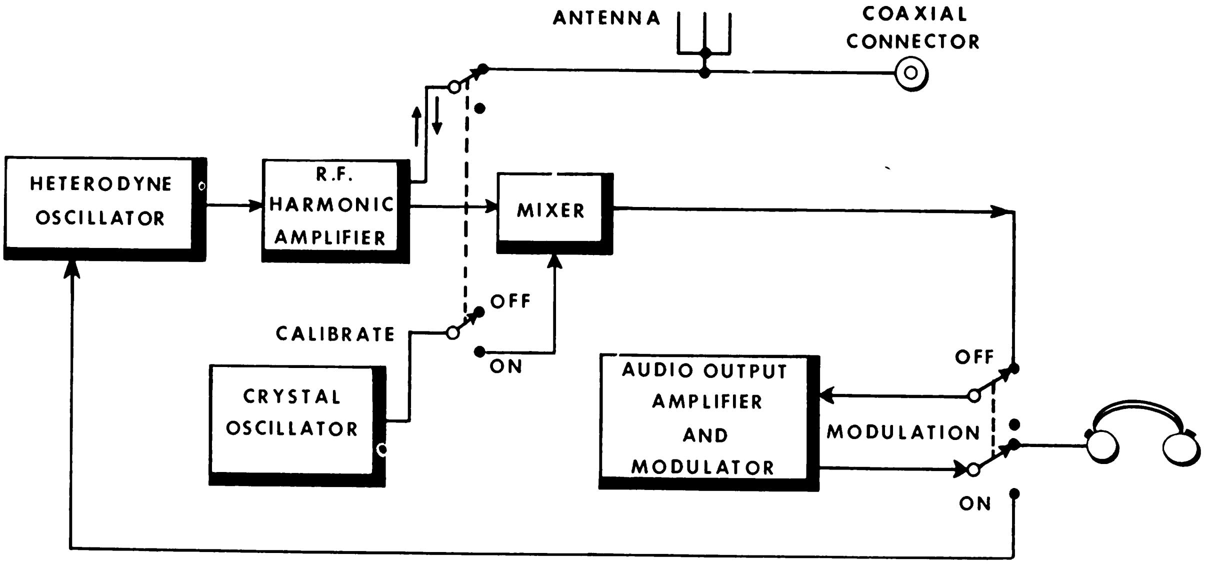


Figure 7-24.—Block diagram of typical heterodyne frequency meter.

In figure 7-25 is illustrated a typical frequency meter in common use for the test and adjustment of aircraft electronic equipment operated in the frequency range of 20 to 450 megacycles. The chassis is shown removed from the carrying case. The calibration book necessary for accurate operation of the instrument is located in the open cover. This instrument is designed for either battery or auxiliary power supply operation. This, combined with its light weight and high accuracy, makes it easily adaptable for shop, line, or aircraft use.

The schematic wiring diagram of the TS-323/UR heterodyne frequency meter is shown in figure 7-26. As shown in the figure, the heterodyne oscillator utilizes a triode (V101) in a modified Hartley circuit. The frequency determining elements are L101, C101, C102, and C103, all connected in parallel. C101 is a corrector capacitor adjustable from the front panel by means of the CORRECTOR control knob and is used for correction of the oscillator frequency to that of the crystal oscillator. Trimmer capacitor C102 allows internal correction adjustment beyond the range of the corrector capacitor (C101). C103 is the main tuning capacitor for tuning the heterodyne oscillator over a fundamental range from 20 to 40 mc. The remainder of the frequency range is obtained by use of harmonics up to the twelfth.

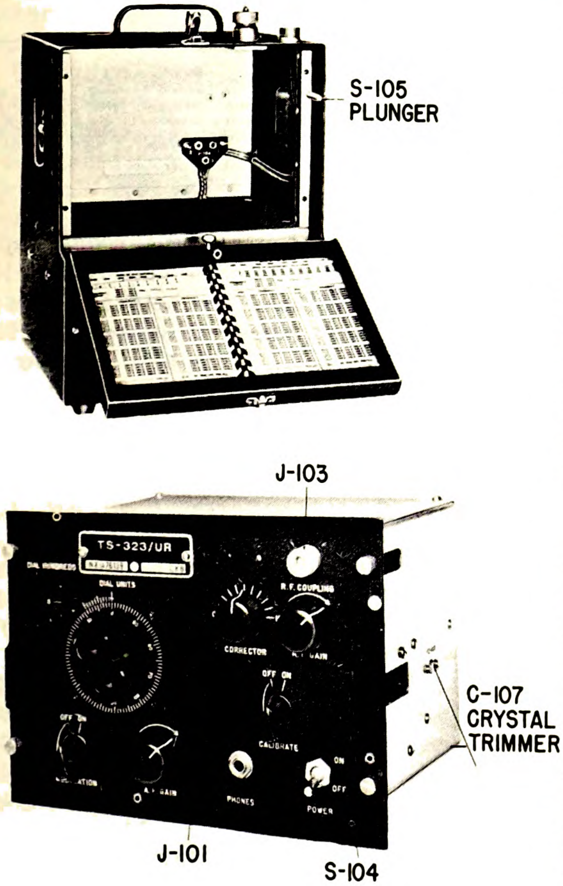


Figure 7-25.—TS-323/UR heterodyne frequency meter.

The RF output from the heterodyne oscillator is coupled into the distortion or harmonic amplifier stage (through C106) which contains a pentode tube, V102. Some grid bias is obtained by means of R102 which functions as a conventional grid leak, producing bias by means of the voltage drop from rectified grid current. Since no cathode bias is used and any positive signal applied to the grid is clipped, a new wave, rich in harmonics, results. The low value (47 ohms) of R105, the plate-load resistance, is required to match the amplifier output to the impedance of the antenna coupling network.

Capacitor C110 couples the output from the RF distortion amplifier into the antenna coupling network, or couples the antenna coupling network through capacitor C111 to the control grid of the mixer (V104), depending on whether the frequency meter is being used to generate or to receive signals. The antenna coupling network consists of a short length of 50-ohm coaxial cable and a 500-ohm potentiometer (R104) which is the RF gain control. It is adjustable on the front panel. Since only one of the output connections (antenna or coaxial cable connector J103) will be used at a time, they are both wired directly to the arm of the RF gain control potentiometer.

The triode, V103, is connected in a conventional crystal oscillator circuit operating at a fixed frequency of 1,000 kilocycles. C107 is a trimmer capacitor for the quartz crystal and provides an internal adjustment for setting the crystal frequency very close to 1,000 kilocycles. Grid leak bias is obtained through R103. C108 increases the effective grid-cathode capacitance of V103 to an optimum value required for the crystal and crystal holder. R108 is a voltage-dropping resistor connected so that V103 will not oscillate when the calibrate switch, S101, is in the OFF position. This resistor allows V103 to draw plate current without oscillating, thus keeping a constant load on the "B" batteries for both

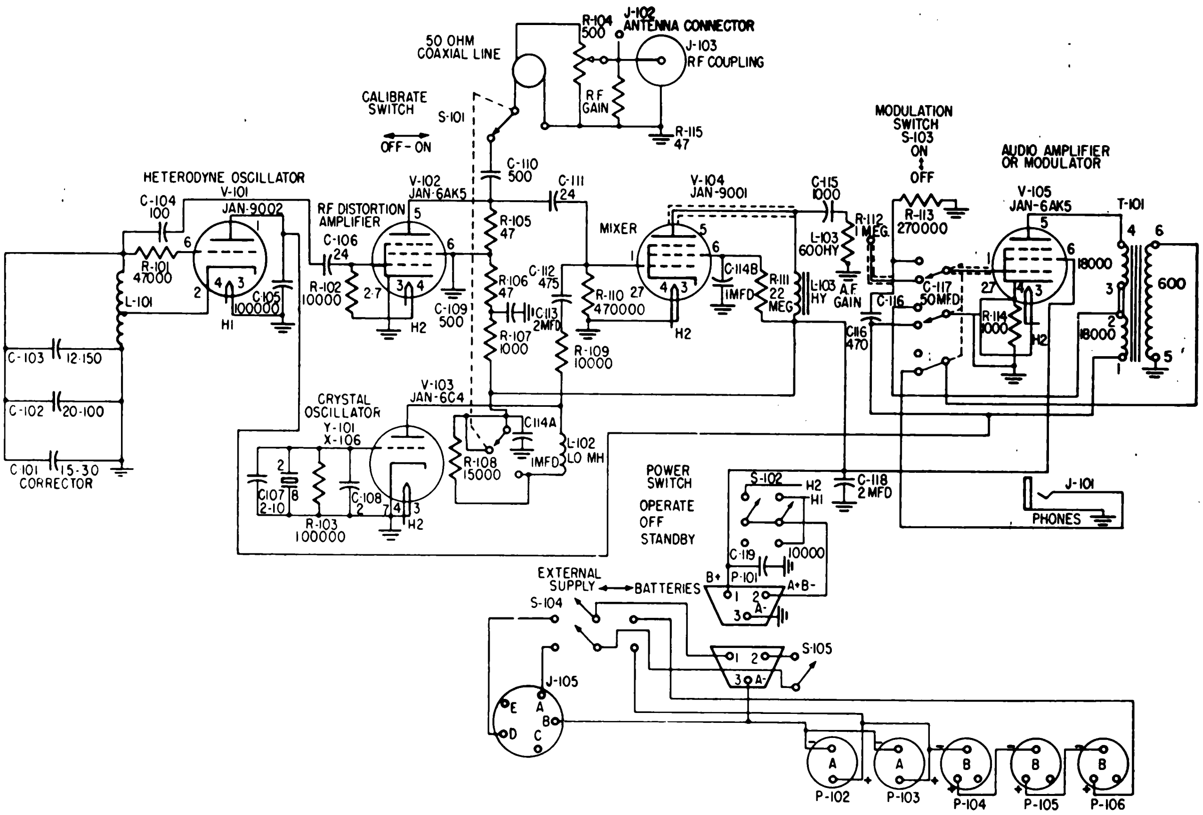


Figure 7-26.—Schematic of TS-323/UR.

positions of the calibrate switch. Improved plate voltage regulation is thereby obtained.

The necessary plate-load impedance for the oscillator is obtained from the untuned plate inductance *L*102. Since the plate circuit is untuned, nonresonant effects are present and many harmonics of the fundamental crystal frequency are generated which provides several crystal check points for calibrating the heterodyne oscillator. With the calibrate switch ON, the output from the crystal oscillator is coupled into the heterodyne mixer grid circuit through limiting resistor *R*109 and coupling capacitor *C*112. This coupling arrangement prevents overloading the mixer with a strong signal from the crystal oscillator.

A pentode, *V*104, is used as a mixer. The voltage developed across the RF harmonic amplifier plate-load resistor *R*105 is coupled into the control grid of the mixer through a small fixed capacitor, *C*111. With the calibrate switch OFF as shown and the crystal oscillator disabled, signals from the antenna coupling network are also coupled into the grid circuit of the mixer through capacitors *C*110 and *C*111. With the calibrate switch ON, the mixer combines the heterodyne oscillator output with crystal oscillator output for calibration purposes. This also disconnects the antenna coupling network from the instrument, thus preventing the generation of spurious beat notes that might be caused from external signals picked up by the antenna. The audio beat-frequency (difference) voltage resulting from the combined RF signals at the control grid appears across the plate-load inductance *L*103. This AF signal is coupled through capacitor *C*115 to the grid of the audio output amplifier.

The pentode, *V*105, is either an audio output amplifier or a modulator, depending upon the position of the modulation switch *S*103. With the modulation switch OFF, this stage functions as an audio amplifier. The mixer output is coupled through *C*115 to the grid circuit of *V*105. The potentiometer *R*112 controls the input to the stage through the front panel AF gain control adjustment. Cathode resistor *R*114 and *C*117 supply proper bias for class A operation. The output of *V*105 is fed into the primary winding of *T*101. The winding ratio of this transformer is such that the tube output impedance is properly matched with a 600-ohm load.

With the modulation switch ON, *V*105 functions as an audiofrequency modulator with the grid connected to coupling capacitor *C*116. This capacitor also serves as a blocking capacitor for direct current and *R*113 provides a grid return to cathode. The auxiliary winding (terminals 1 and 2) is inductively coupled to the plate winding (terminals 3 and 4) thus permitting the stage to oscillate at about 1,000 cycles. The second section of the modulation switch *S*103 connects the B+ of the heterodyne oscillator in series with the auxiliary winding of *T*101 with the result that the plate circuit of the oscillator is modulated at an audiofrequency rate. The third section of the modulation switch disconnects the secondary winding of the output transformer from the phone jack so that the AF modulator output will not be heard in the headphones.

The power input circuit is wired so that either internal batteries or an external power supply may be utilized through the use of the D. P. D. T. switch *S*104. *J*105 is the external power input plug wired to the power changeover switch *S*104. *J*104 is a female battery power receptacle located in the frequency meter carrying case. *P*101 is the corresponding male plug mounted on the back of the frequency meter chassis so that it will plug into *J*104 when the chassis is put into the carrying case.

Two 6-volt "A" batteries connected to *P*102 and *P*103 (in parallel) and three 45-volt "B" batteries connected to *P*104, *P*105, and *P*106 (in series) are required for battery operation. A total B+ voltage of 141 volts is obtained (pin 1 of *P*101) by connecting the "B" battery supply (135 volts) in series with the "A" battery supply (6 volts). The batteries are stowed in the carrying case beneath the chassis and are accessible along with spare parts for the instrument from the back of the carrying case.

Switch *S*102 is the power switch located on the control panel. This switch has three positions: STANDBY, OFF, and OPERATE. In the STANDBY position filament voltage is impressed only on the heterodyne oscillator, *V*101, thus limiting current drain during the warmup period. *C*118 and *C*119 are bypass capacitors providing a low impedance path across the power supply which reduces the common coupling between the various frequency meter circuit components. *S*105 is a spring action plunger type switch mounted so that the plunger is actuated by the operating controls compartment cover. Closing the cover pushes the plunger in and disconnects the A+ lead and B- connection from the frequency meter which prevents leaving the power on when the frequency meter is not in use.

Signal Generators

In the maintenance of airborne electronic equipment, it is often necessary to employ standard sources of a-c energy, both audiofrequency and radiofrequency. These sources are called signal generators. They are used in testing and alining radio transmitters, receivers, and amplifiers; they are also used when troubleshooting various electronic devices, and sometimes for measuring frequency.

The principal function of a signal generator is the production of an alternating voltage of the desired frequency and amplitude which has the necessary modulation for the test or measurement in question. It is very important that the amplitude of the generated signal be correct, and in many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the output test signal is coupled into the circuit being tested and its progress through the equipment is traced by the use of high-impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, calibrated networks of resistors, called attenuators, are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are desirable since the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of signal generators. It is possible to classify them roughly by frequency into audio generators, generators of both the audio and video ranges, radiofrequency generators, frequency-modulated RF generators, and special types which combine all of these frequency ranges.

In almost all of these types, electron tube oscillators are used to produce the initial signal. In order to achieve accurate results in the use of the signal source, it is necessary to allow the oscillator circuits to reach a condition of stable operation before applying the output. This condition is reached when the tubes and circuit elements attain the temperature at which the instrument was calibrated. A preliminary warmup should always be given the generator when accurate and stable signals are desired. The minimum warmup time for the generator is contained in the *Handbook of Service Instructions*. The general properties and functions of signal generators were covered in *Basic Electronics*. In the sections immediately following, there is a discussion of the types of generators most commonly used by the Aviation Electronics Technician.

AUDIO AND VIDEO SIGNAL GENERATORS

Audio signal generators produce stable audiofrequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the RF range. These generators are used in testing video amplifiers and other wideband circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control. Voltage regulation circuits are necessary to insure stability of the oscillator in generators which derive power from 115-volt, a-c sources. In portable generators, battery power supplies are usually used and these require no voltage regulation.

In the audio and video generators of the beat-frequency type the output frequency is produced by mixing the signals of two radiofrequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency. For example, if the fixed and variable oscillators both produce a frequency of 400 kilocycles, the resultant output frequency is zero cycles. If the variable oscillator is changed to 401 kilocycles, the resultant is then 1 kilocycle. By action of this type, any desired frequency in the range of the circuits may be produced in the output.

Audio signal generators often include RC oscillators in which the audiofrequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several RC circuits, each corresponding to a portion of the entire range of frequency values. Each circuit is switched into the oscillator to produce its desired portion of the audio range..

The amplifier section of the block diagram of figure 7-27 usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of RC networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.

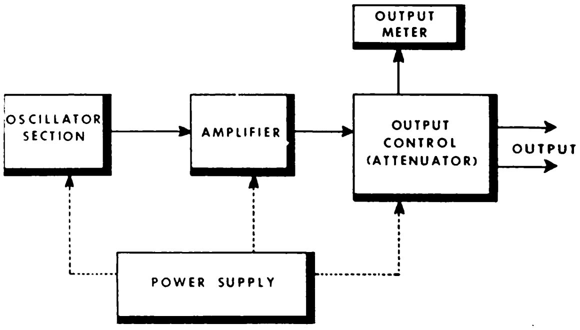


Figure 7-27.—Block diagram of typical audio or video signal generator.

The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal. The settings of the output control knob provide output voltage values which are either inscribed directly on the knob or which can be interpreted by reference to the instruction manual provided with the generator.

RADIOFREQUENCY SIGNAL GENERATORS

A typical radiofrequency signal generator contains, in addition to the necessary power supply, three main sections: an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radiofrequency signal of the oscillator. In addition, most RF generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent signals from the oscillator from entering the circuit under test by means other than through the output circuit of the generator.

A block diagram of a typical RF signal generator is shown in figure 7-28.

The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator is designed. In low-frequency signal generators, the resonating circuit consists of one of a group of coils combined with a variable capacitor. One of the coils is selected with a range selector switch which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

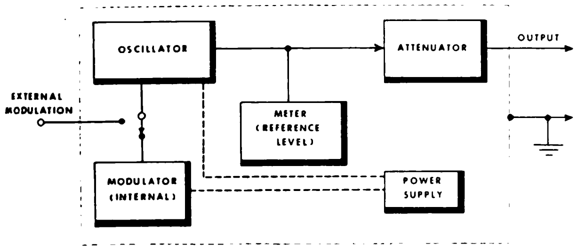


Figure 7-28.—Block diagram of a radiofrequency signal generator.

In signal generators designed for the higher frequencies, the resonating circuits are usually in the form of butterfly tuning circuits and resonant cavities. Reflex klystron oscillators are also used frequently in generators of frequencies above 1,000 megacycles.

In any signal generator, it is required that the oscillators have good stability both in frequency and amplitude over a wide range of output frequencies.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the RF signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In some signal generators, either of these methods of modulation may be employed. In addition a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired. The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one. The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is often calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0) the reading on the attenuator knob gives the exact value (no multiplication factor) of the output in microvolts. If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one, and this decimal is multiplied by the attenuator reading to give the output in microvolts.

RF Signal Generator SG-85/URM-25D

Figure 7-29 shows one of the RF generators you will be using in the fleet. It is intended primarily for bench testing of electronic equipment, covering the frequency range from 10 kc. to 50,000 kc. This frequency coverage is accomplished in eight bands, and the RF output can be either modulated or unmodulated. The frequency generated can be read from a main frequency scale within an accuracy of ±0.5 percent, and by proper use of a 1 mc. internal crystal calibrator the accuracy can be increased to 0.05 percent above 1 mc.

This test set also generates an audio signal of 400 or 1,000 cycles to modulate the RF carrier. The audio signals are also available at the front panel.

Operational procedure, technical characteristics, and theory of the SG-85/URM-25D can be found in NavShips 92134(A), the instruction book for the generator. This instruction book will be available in technical libraries of supporting activities that use the test set.

FM Signal Generators

Frequency-modulated RF signal generators are widely used for testing frequency-modulated

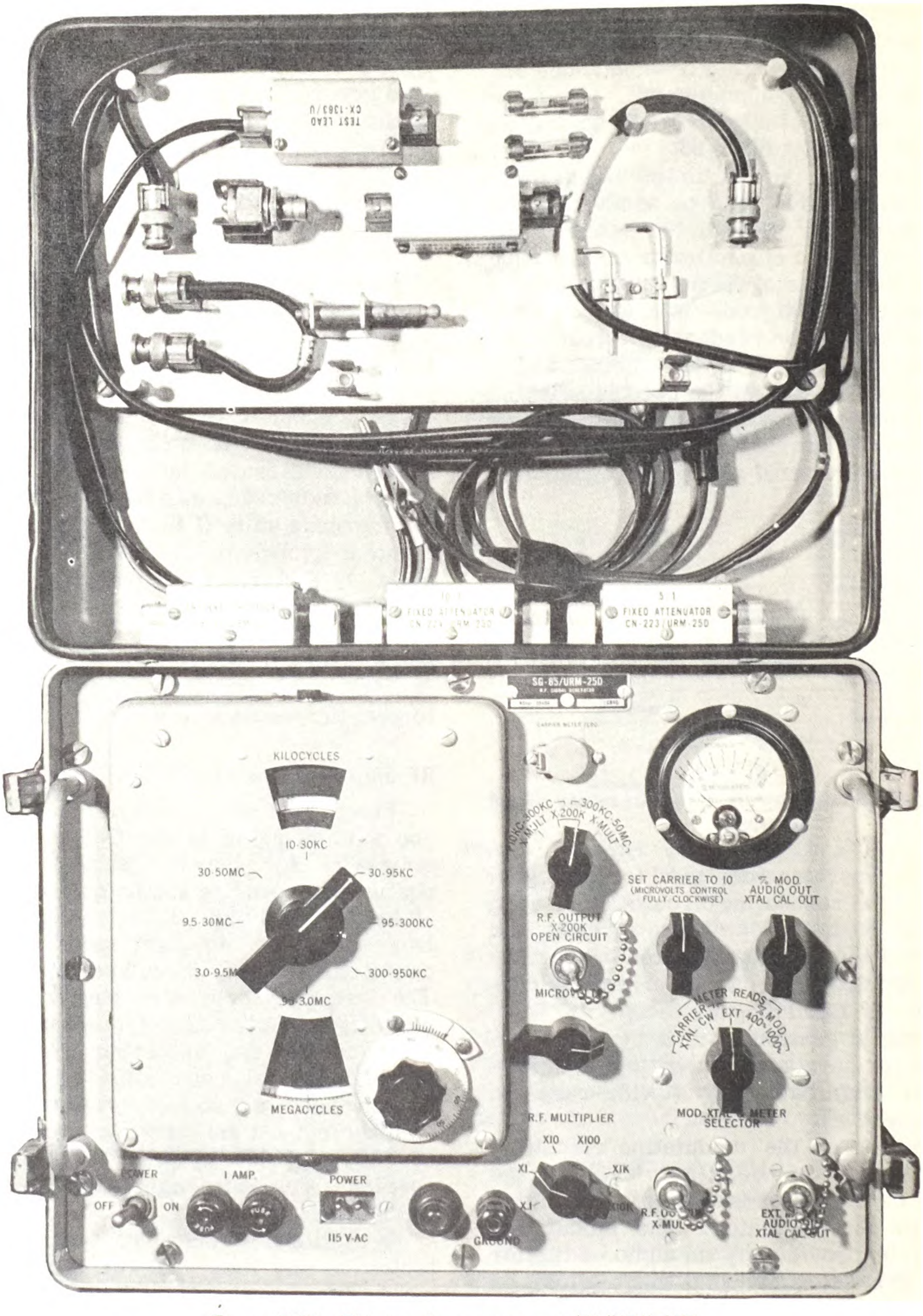


Figure 7-29.—RF signal generator set AN/URM-25D.

receivers and for visual alinement (using an oscilloscope) of AM receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies above and below a given center frequency value. The overall frequency change is called the frequenc swing.

There are several methods by which the frequency of the oscillator in the signal generato may be frequency-modulated. In one type of F generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loudspeaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audiofrequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated. A reactance tube is an electron tube in which the plate current is made either to lead or to lag the plate voltage variations by 90 degrees. Because of this phase difference, the plate circuit of the tube is electrically equivalent either to a capacitor or to an inductance. The modulating voltage is impressed on the grid of the reactance tube, causing the capacitive (or inductive) reactance of the plate circuit of the tube to vary. Since the reactance tube plate circuit is a part of the oscillator tuning circuit, variation in the reactance value causes the generated frequency to vary in step with the modulating voltage.

In signal generators of microwave frequencies, frequency modulation is easily accomplished in the oscillator by applying the modulating voltage to the repeller plate of the reflex klystron tube which is usually employed in these generators.

Wavemeters

Wavemeters are calibrated resonant circuits used to measure frequency. Although the accuracy of wavemeters is not as high as that of heterodyne frequency meters, they have the advantage of being comparatively simple and can be easily carried about.

Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low-frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters: the absorption, the reaction, and the transmission types. Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency. The setting of the wavemeter dial is made by observing the grid-current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies.

In figure 7-30 a typical cavity wavemeter is illustrated.

The wavemeter illustrated is of the type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q LC tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, (A) or (D). A crystal rectifier then detects or

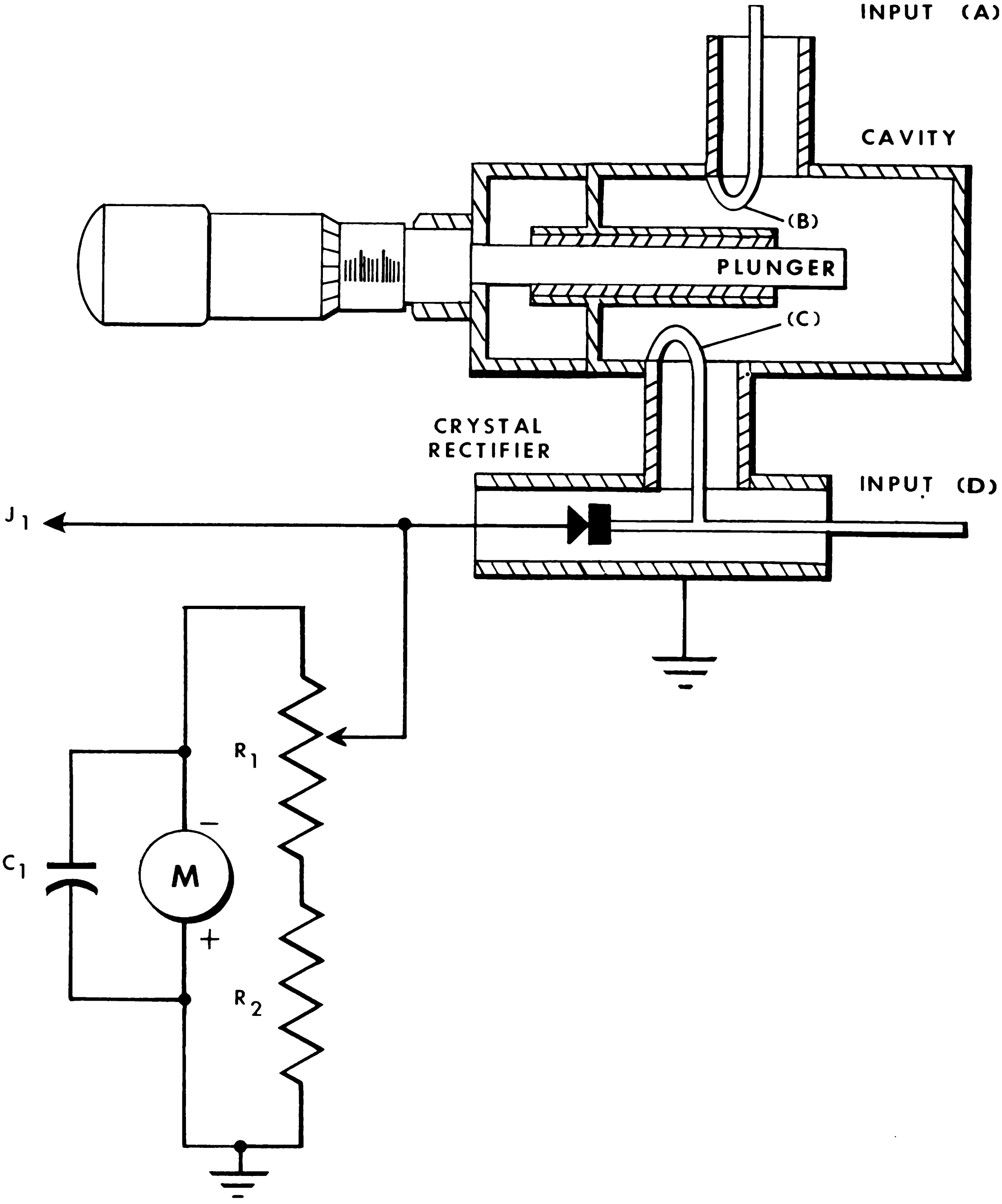


Figure 7-30.—Typical cavity wavemeter.

rectifies, the signal and the rectified current is indicated on the current meter, M.

The instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input (A). When the cavity is tuned to the resonant frequency of the sig energy is coupled through coupling loop into the cavity and out through loop (C) to crystal rectifier where it is rectified and indicated on the meter. At frequencies resonance little or no current flows in detector and the meter reading is sm

Therefore, the micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input (D). The RF loop (C) then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the current indicated on the meter dips. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter, and the resonant frequency is determined from the micrometer setting and the calibration chart.

The potentiometer, *R*1, is used to adjust the sensitivity of the meter from the front panel of the instrument. *J*1 is a video jack and is provided for observing video waveforms with a test oscilloscope.

A directive antenna is used in conjunction with the instrument for making relative field strength measurements of radiated signals, for use in measuring the frequency of radar transmitters, and for constructing radiation patterns of transmitting antennas.

In radiation pattern measurements, the directive antenna is connected to the wavemeter input and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper and the field pattern thereby determined.

Power Absorption Cones

The primary purpose of a power absorption cone is to provide an absorbing shield for radar transmitting antennas to prevent radiation. By absorbing the RF energy, reflections from nearby objects which cause erratic operation of the radar under test are thereby prevented.

A typical power absorption cone is illustrated in figure 7-31.

The cone consists of a pickup horn, shown at 1 of figure 7-31, mounted at the apex of a pyramid, 2. The pyramid is constructed in such a way as to absorb energy radiated from the system under test. The inner walls of the pyramid are lined with a material that has high absorbing qualities, so that the radiation that does not fall on the horn will be absorbed. Power picked up by the horn may be connected into an echo box or other test device.

An absorbing screen is often used when it is desired to operate a radar in an enclosed

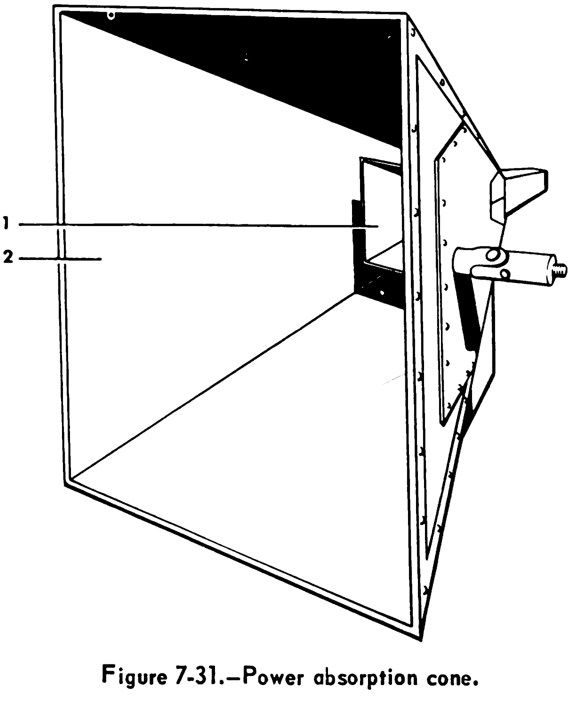


Figure 7-31.—Power absorption cone.

space. The purpose of the absorbing screen is to absorb the radiated energy from the radar transmitter under test and this prevents high-power reflections from being returned to the radar system or to other radars. The screen usually consists of a number of straight expanded hard rubber panels and is mounted in front of the radiating antenna.

Echo Boxes

An important part of the work of the AT consists of performing tests to determine the operating characteristics of airborne radar sets. The following section is related to the general principles of radar operation as discussed in *(Basic Electronics,)* and is a brief discussion of the use of a device which is often employed for making specific tests of the overall performance of a radar installation.

Under field conditions it is difficult to check the operation of radar equipment because of the absence of standard signals. The use of normal return signals is undesirable for purposes of adjustment and measurement because these signals vary considerably with atmospheric conditions and with the nature of the physical surroundings. A device which is frequently used to supply standard reference signals is the echo box.

An echo box is a tunable resonant cavity which has a very high Q. All resonant cavities operate similar to the one in figure 7-30, which acts as a high-Q tank circuit. The cavity is equipped with coupling loops, either a dipole or a coaxial horn antenna, a crystal detector, a microammeter, and several sections of transmission line. The cavity is tuned by means of a movable plunger which is mechanically connected to a calibrated tuning dial. The echo box receives energy from the radar transmitter either by use of a pickup dipole (or horn) or by connection through a cable to a directional coupler in the transmission line of the radar set.

Echo boxes are used in measuring the overall performance of radar sets, in making spectrum graphs of magnetrons, for measuring the relative power output of radar transmitters,

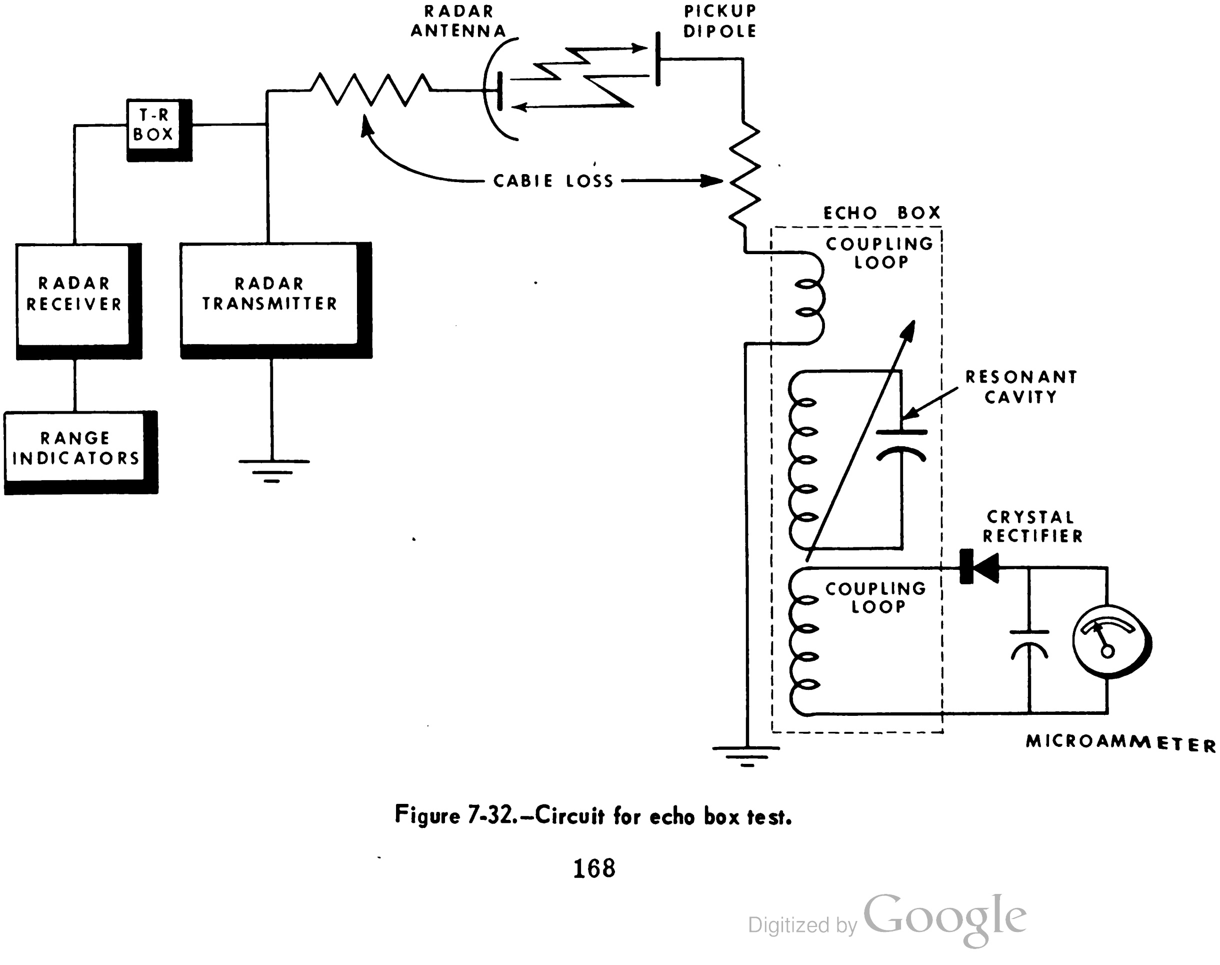


Figure 7-32.—Circuit for echo box test.

and for checking the frequency of the transmitter and of the local oscillator.

The basic circuit for making echo box tests is shown in the block diagram of figure 7-32.

In measuring the overall performance of radar sets, some of the energy generated by the radar transmitter is picked up by the directional coupler or by the pickup dipole and applied to the echo box. This energy excites oscillations in the echo box which persist for some time after the end of the radar pulse. (See fig. 7-33.) These oscillations gradually die out because some of the power is radiated back to the radar set and the rest of it is dissipated in the echo box cavity and in the output meter circuit. The part of the energy that is fed back to the radar antenna causes a signal to appear on the radar indicator.

Figure 7-34 illustrates three typical ringing time indications similar to those in overall performance checks made with echo boxes.

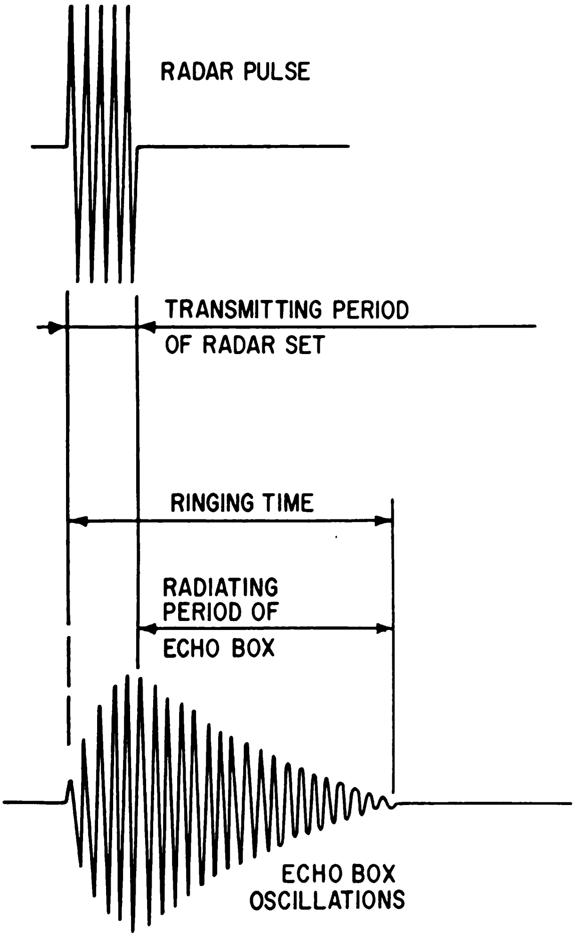
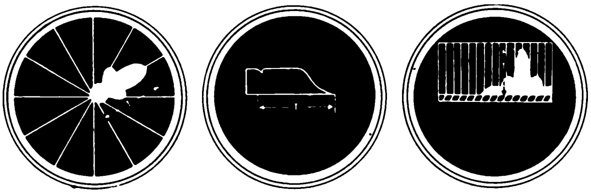

RADAR PULSE
TRANSMITTING PERIOD OF RADAR SET
RINGING TIME
RADIATING PERIOD OF ECHO BOX
ECHO BOX OSCILLATIONS

Figure 7-33.—Relationship between radar pulse and echo box oscillations.


PPI SCAN A SCAN B SCAN

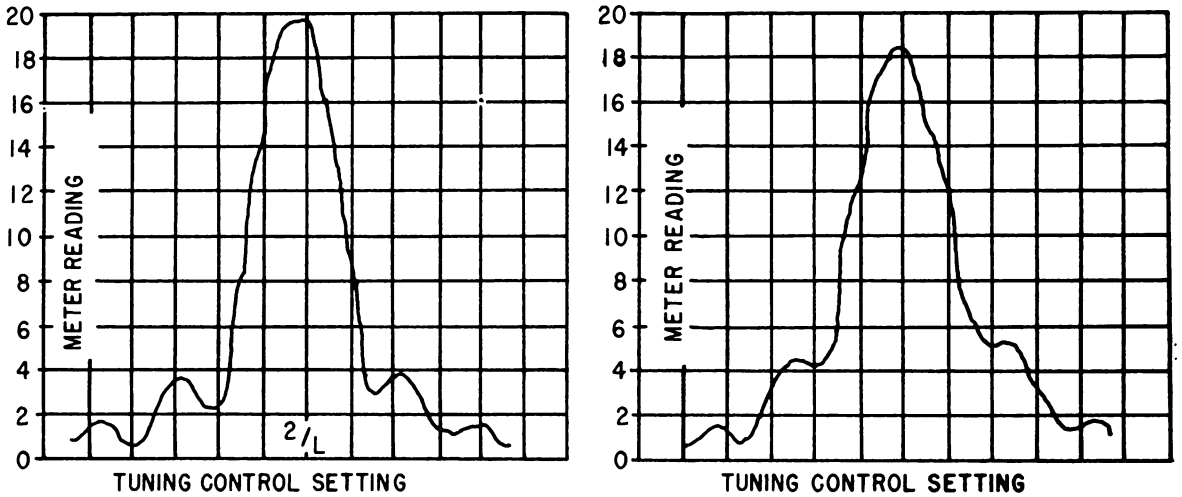
T= RINGING TIME

Figure 7-34.—Ringing time indications.

The flat shape of the pattern on the A-scan is the result of saturation by the strong signal.

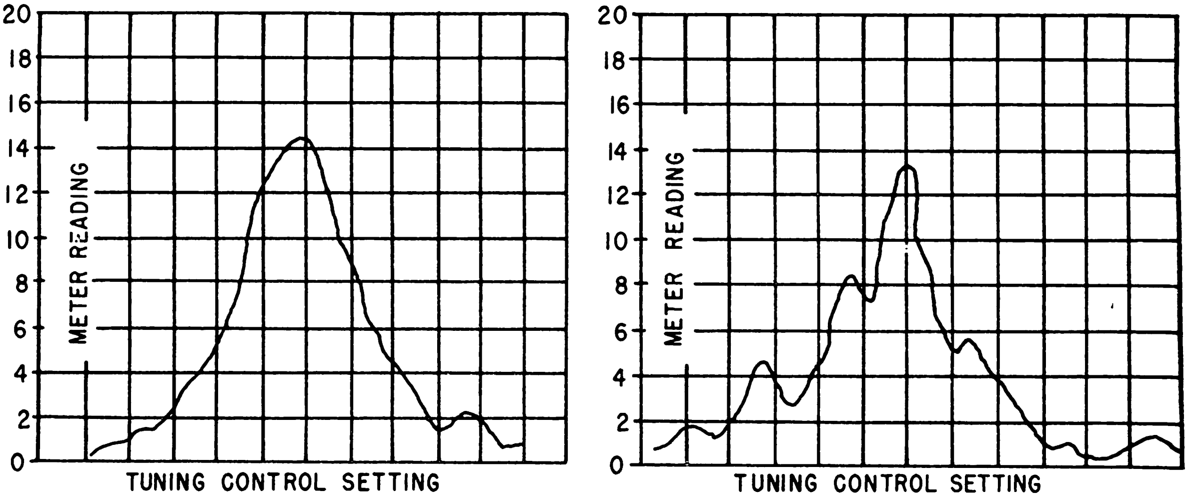
The time between the start of the transmitted pulse and the time when the returned energy from the echo box falls below the minimum value required to give an indication on the radar indicator is called the ringing time. The ringing time duration depends upon the pulse width and power output of the transmitter and the sensitivity of the receiver. The longer the ringing time, the better is the overall performance of the system. Each radar set has a minimum performance ringing time and this value provides a standard for use in checking the operation of the set. The value of the minimum ringing time for a particular radar can be found in the appropriate manual of operating instructions.

Echo boxes are often used in making spectrum graphs of transmitter output. Each time a radar transmitter generates an RF pulse, it produces electromagnetic energy in the form of electromagnetic waves. Not all of these waves are of the same frequency. Some of the energy is radiated at the frequency to which the transmitter is tuned and the remainder is distributed in frequencies which are higher and lower than the tuned frequency. A spectrum graph showing the values of the frequencies present and their relative strength can be made by tuning the echo box across the entire range of frequency values in the output of the transmitter. The readings of the output meter in the echo box are plotted against frequency values in the spectrum which are read from the calibrated dial of the instrument. A radar transmitter in satisfactory condition gives a spectrum graph which is a peak with the sloping sides symmetrical and containing several smaller peaks separated by well-defined minimum values. A curve without well-defined minimum values indicates that the transmitter output is frequency-modulated during the pulse. (See fig. 7-35.)



A-GOOD SPECTRUM

B-FAIR SPECTRUM



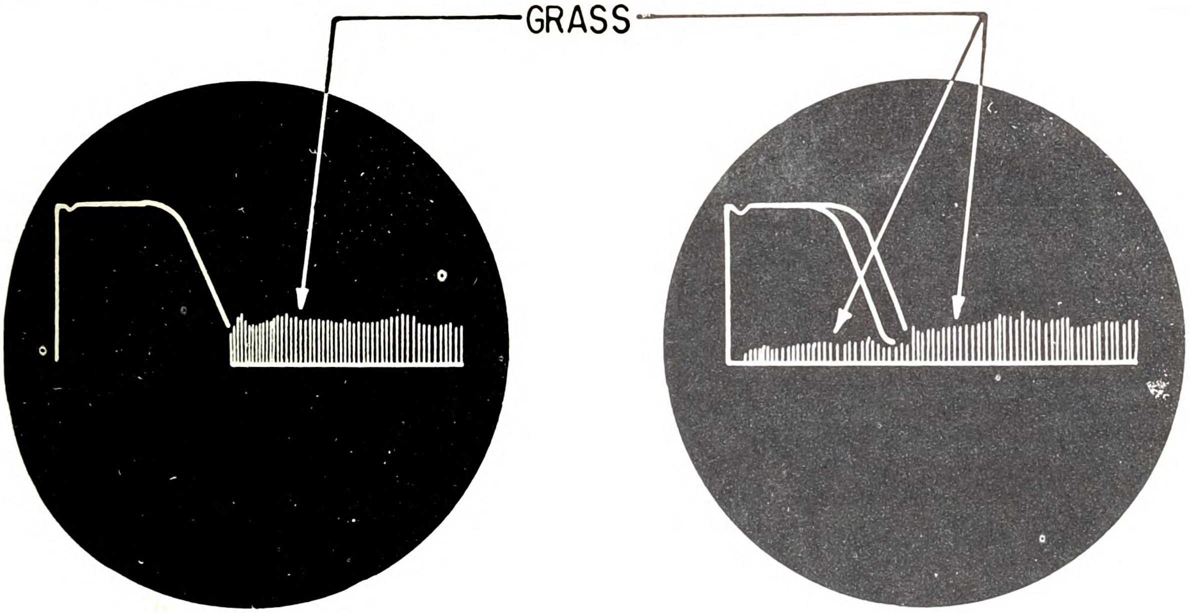
C-POOR SPECTRUM

D-BAD SPECTRUM

Figure 7-35.—Representative spectrum graphs.

The echo box can be used to measure the relative power output of radar transmitters. The amount of energy delivered to the resonant cavity of the echo box depends on the average power of the radar pulse, the pulse length, the amount of loss in the directional coupler or pickup dipole, and the amount of loss in the connecting cables. The echo box is tuned to give a maximum reading of the output meter. The meter coupling circuit is then adjusted so that the maximum reading falls on the approximate center of the scale, and this value is recorded to be used as a reference. After adjustments on the transmitter are made, the readings of the echo box output meter are compared with the reference value to determine the effects of the adjustments on the output power.

Multiple moding, which is an abrupt and irregular jumping from one frequency to another, sometimes occurs in microwave radar equipment. This effect is readily detected with the echo box. The indication of multiple moding is an erratic ringing time pattern containing several background noise traces in the pattern. (See fig. 7-36.)



NORMAL MODING
(A)

MULTIPLE MODING
(B)

Figure 7-36.—Indications of multiple moding on A-scope.

The transmitter frequency and the frequency of the receiver local oscillator can be measured by using the echo box as a wavemeter. In addition to these checks, the device can be used in measuring the signal-to-noise ratio, for testing the operation of the automatic frequency control, for measuring the TR box recovery time, the receiver recovery time, and the amount of loss in transmission lines. For these test measurements the instruction book for the particular echo box in use must be consulted.

Video and Pulse Generators

All signal generators have one thing in common—they generate a signal (or signals) for external use. The generation of these signals involves many fundamental electronic circuits and some special-purpose tubes. Some of the circuits involved are multivibrators, limiters, clampers, discriminators, oscillators, and sawtooth generators. One of the special-purpose vacuum tubes is the reflex klystron, which is used as an oscillator. The detailed theory of these fundamental circuits and tubes is beyond the intended scope of this training course, but attention is invited to the fact that they are discussed in *Basic Electronics*, NavPers 10087, and in the training course *AT 1 & C*. The TS-622 is typical of the generators that you will use.

SIGNAL GENERATOR TS-622

The TS-622 is a signal generator of low power output and is used in the maintenance of radio and radar equipment operating in the frequency range between 7,000 and 10,750 megacycles. (See fig. 7-37.) It produces continuous-wave, pulse-modulated, and frequency-modulated signals. The output frequency and power level of the test set are indicated on separate direct-reading dials located on the front panel.

In the pulse-modulated mode of operation pulse widths of 0.5 to 10 microseconds may be obtained, and the pulse repetition may be adjusted from 40 to 4,000 pulses per second. Pulse modulation is obtained from a

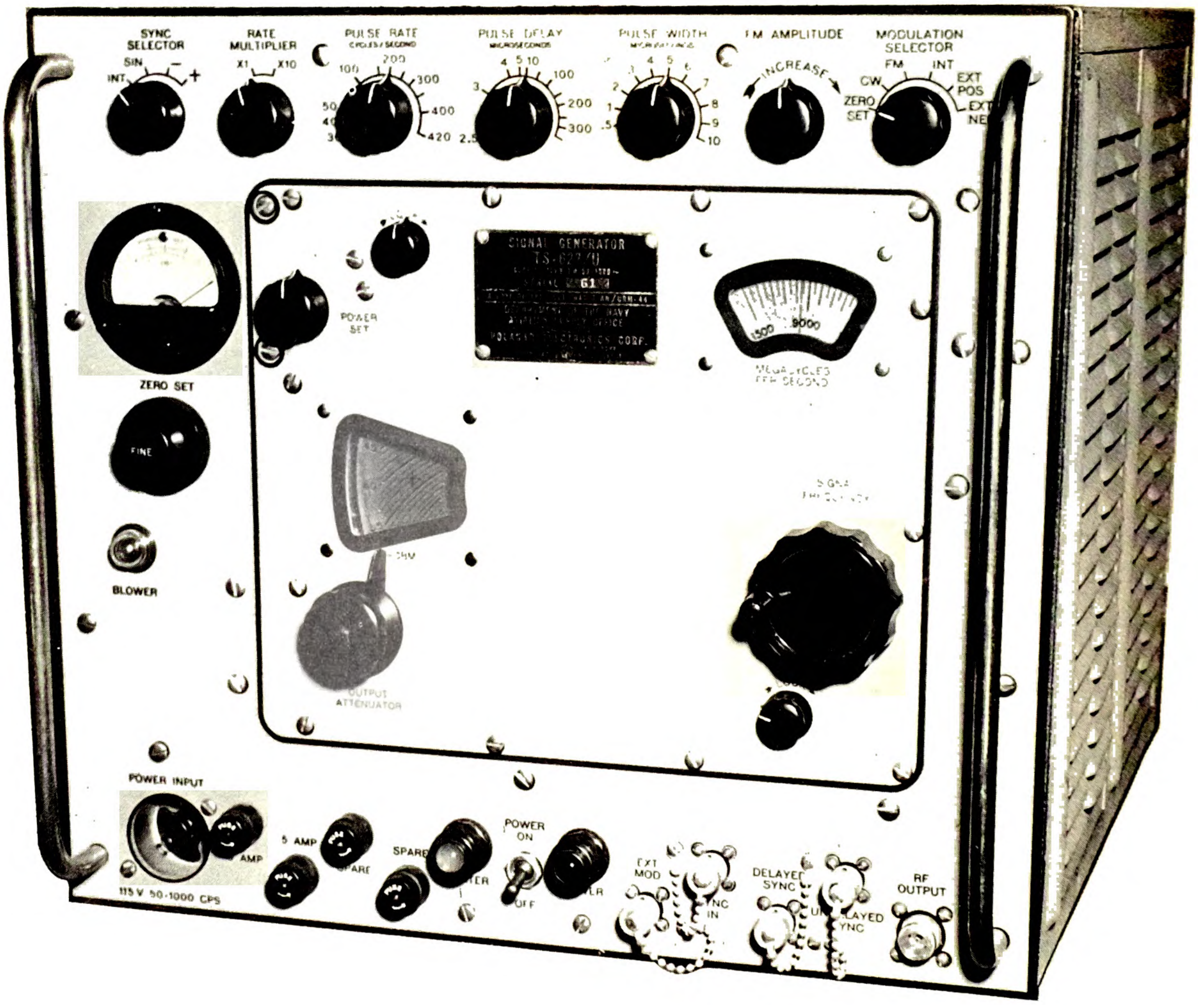


Figure 7-37.—Signal generator TS-622.

multivibrator which produces square waves of the above mentioned pulse widths and frequency.

In the frequency-modulated mode of operation a sawtooth generator supplies a sawtooth of voltage to the reflex klystron to cause the signal to be frequency modulated.

In the CW mode of operation the klystron is permitted to free-run at the frequency selected.

This test set includes an internal synchronizing generator (the multivibrator), and has provision for applying an external synchronizing signal of either positive or negative polarity. It also has provision for an external modulating signal to be applied.

The front panel provides three outputs. These are (1) the RF output which is the output from the klystron oscillator; (2) an undelayed sync (undelayed synchronizing voltage) and (3) a delayed sync. The syncs are outputs from the internal sync generator or the external sync signal.

The *Handbook of Service Instructions*, AN 16-30URM44-2 contains a breakdown of all circuits of the test set and detailed theory of operation of each. Also included is a master block diagram to simplify the explanations.

Crystal Rectifier Testing

The function of a crystal rectifier test set is to provide a quick and accurate means of testing a crystal rectifier in the field. Although the complete testing of a crystal rectifier is an elaborate procedure requiring precision radiofrequency test equipment, the test sets usually provided are sufficient for determining whether or not the crystal rectifier is satisfactory for use. Crystal testing is accomplished by measurement of the forward and backward resistance, and usually the back current at 1.0 volt.

A crystal rectifier is a device used for converting RF energy into unidirectional current. It usually consists of a small piece of silicon in contact with a thin tungsten wire (called a cat whisker), both of which are mounted in a small cartridge-type container.

The rectification takes place at the contact between crystal and cat whisker, and is due to the fact that the resistance in one direction is greater than that in the other direction, as in a vacuum tube used as a rectifier or detector. The properties of the rectifier depend critically on the type of contact area, and the place of contact. The crystal rectifier has been carefully adjusted at the factory, and should not be upset by tampering with the setscrew.

A crystal rectifier is illustrated in figure 7-38. The crystal is designed so that current flows from the tip to the base (tungsten to silicon). The area of contact within the crystal rectifier housing is very small, and if too much current is passed through the cartridge, the resulting heat will damage it, causing the operation of the crystal rectifier to be impaired or the unit to burn out completely.

Crystal rectifiers may be damaged by static discharges. The operator should be sure that any static charge which may be present on the body is discharged by momentarily touching (grounding) a finger or the hand to the ground contact of the test set or equipment in which the crystal is to be installed.

Because of the possibility of damage due to strong RF fields which may be present, crystal rectifiers are stowed in metal containers or in metal foil except when they are being tested or used.

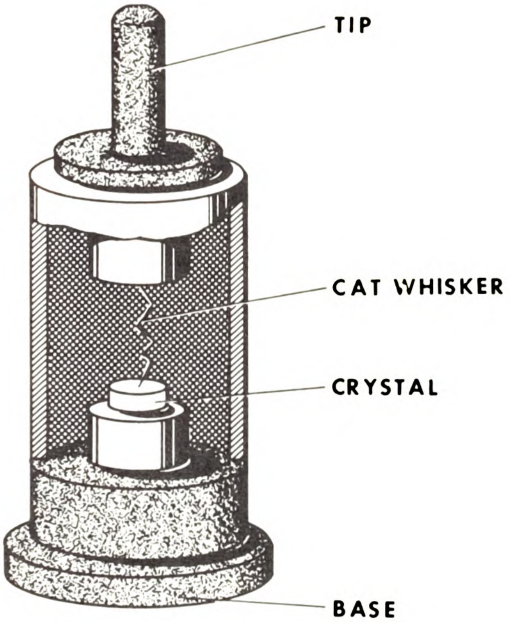


Figure 7-38.—Crystal rectifier.

The circuit diagrams of a typical crystal rectifier test set are illustrated in figures 7-39 and 7-40. The figures show two arrangements of the same device. The test set can be changed from the resistance measuring arrangement to the back-current circuit by the action of a selector switch. The meter shown in the two figures is calibrated for both resistance and current measurements. It contains a 0-1 milliampere movement with an internal resistance of approximately 100 ohms.

The circuit shown in figure 7-39 is used for forward and backward resistance determination and is similar to the circuit of a simple ohmmeter. With switch *S*1 set to the ZERO ADJUST position, the milliammeter is first set for maximum (1.0 ma.) current, or zero indicated resistance, by adjustment of the series potentiometer *R*102. The forward and backward resistance can then be measured by rotating *S*1 to the appropriate position and placing the crystal rectifier in the proper holder. If no further change has been made in the position of the control *R*102, the additional resistance which the crystal rectifier introduces into the circuit causes a decrease in the current flow, and the meter will then deflect to some point on the scale other than full deflection.

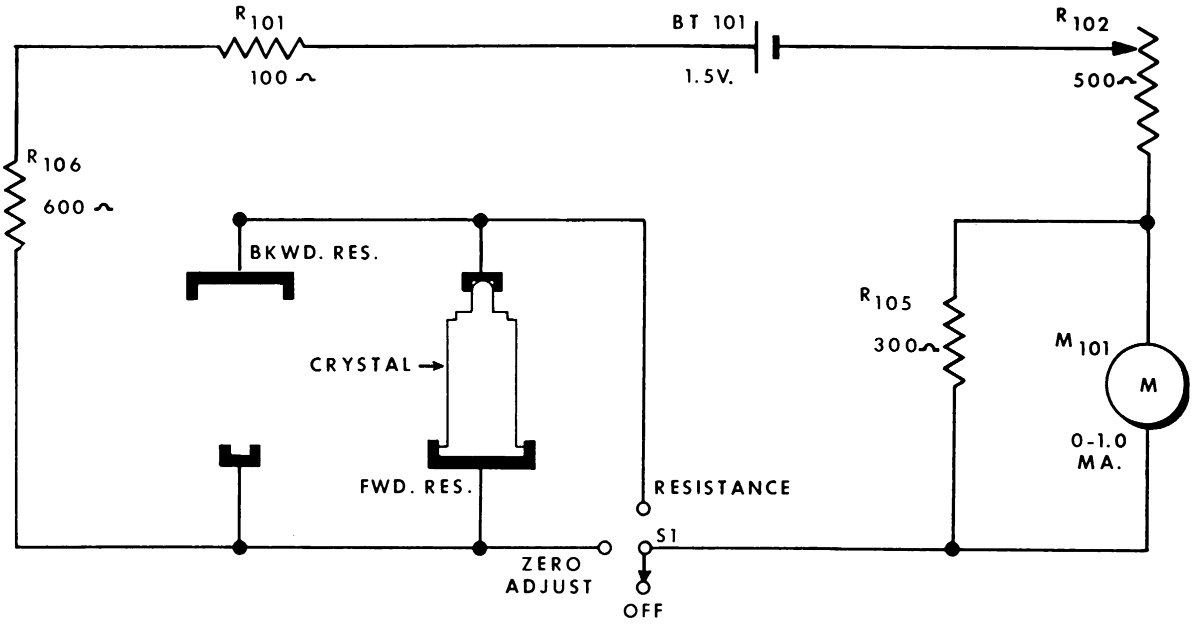
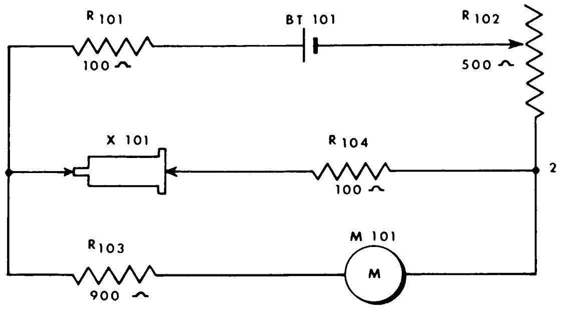
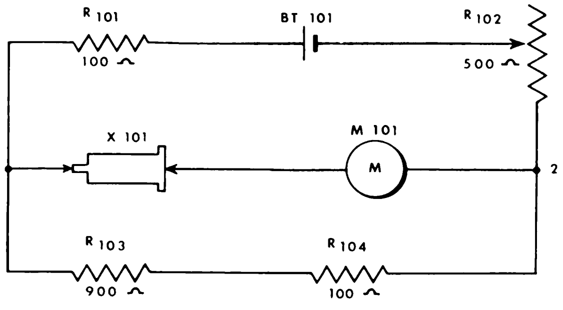


Figure 7-39.—Rectifier test set schematic—resistance measurement.



(A) BACK CURRENT ZERO ADJUSTMENT



(B) BACK CURRENT

Figure 7-40.—Rectifier test set schematic—back current measurement.

The forward, or "front," resistance of the crystal is the resistance measured with normal current flowing (comparable to the cathode-to-plate current flow in a diode vacuum tube). The crystal rectifier is considered unfit for use if this resistance is greater than 500 ohms.

The backward, or "back," resistance of the crystal is a measure of resistance to current flow from the crystal to the whisker in the rectifier. This current flows from the rectifier base to the tip and is comparable to any current flowing from the plate to the cathode in a diode vacuum tube. The crystal rectifier should be rejected for use if the ratio of back resistance to front resistance is less than 10 to 1.

For example, if the meter reading is 400 ohms when the forward resistance is measured, then the back resistance must be 4,000 ohms or more if the crystal is considered to be usable.

In addition to the circuit arrangement for checking the resistance ratio of the crystal rectifier, many test sets are provided with means for measuring the back current through the rectifier with an applied voltage of 1.0 volt. This is a more accurate measure of the condition of the crystal than the resistance-ratio check. The circuit arrangements for this check are illustrated in figure 7-40. In (A) of the figure, the circuit is shown in the condition used for the initial voltage adjustment.

Before the back current is measured, the meter must be adjusted so that an effective voltage of 1.0 volt is impressed across points 1 and 2. Since the back resistance of a crystal rectifier is a high value, the effective resistance of the parallel circuit between points 1 and 2 in (A) of the figure is essentially that of the meter and *R*103, or 1,000 ohms. The full-scale reading of the milliammeter is 1.0 milliampere; therefore, an adjustment of *R*102 resulting in full-scale deflection of the meter insures a voltage of 1.0 volt across the parallel circuit.

After the voltage has been adjusted, the circuit is switched to the condition shown in (B) of figure 7-40 to measure the back current. In this condition, the positions of *M*101 and *R*104 are exchanged so that the crystal is now in series with the milliammeter whose resistance is negligible compared with that of the rectifier. With 1.0 volt impressed across this circuit, the meter then indicates the current flowing through the crystal rectifier. The magnitude of this current is inversely proportional to the backward resistance of the crystal. The scale of the meter is usually marked to indicate the maximum limits of back current for the crystal rectifiers in common use.

The maximum allowable back current varies somewhat with temperature. The lower the temperature, the lower the maximum limit of back current. Temperature correction tables are included with the instruction manuals of most test sets. These should be consulted when the surrounding temperature is considerably lower or higher than 70° F. (approximately 22° C.).

Figure 7-41 shows one type of crystal checker in use in the fleet. Important performance characteristics of crystals may be measured by this tester. These characteristics will largely determine the value of the crystals when used as detectors or mixers. The test set employs a technique using d-c voltage to measure quantities that are mathematically related to crystal performance. It may be used to (1) measure the relative noise figure, (2) obtain an impedance check for selecting matched crystals, and (3) measure sensitivity of crystals.

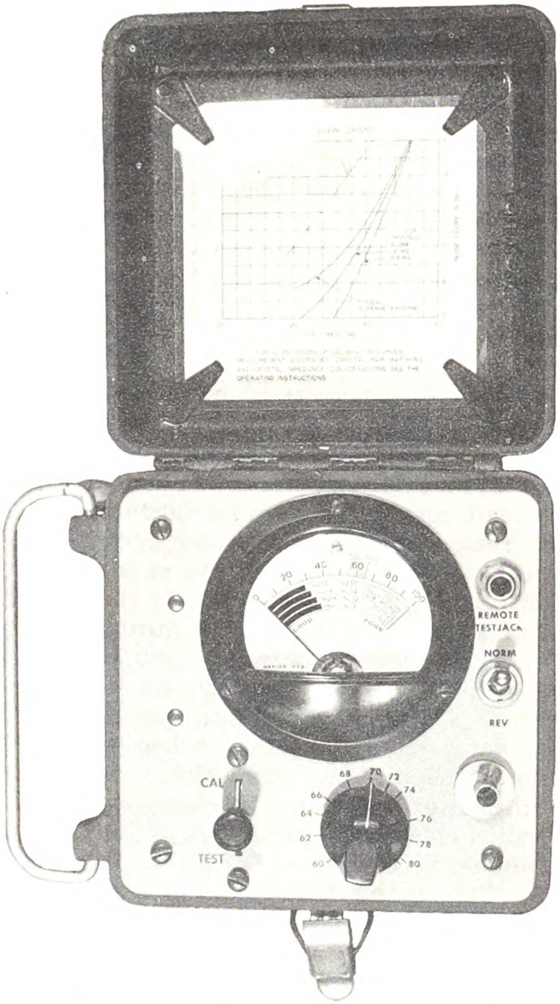


Figure 7-41.—Crystal checker model 21143.

The test set does not indicate effects of shunt capacity or RF impedance of crystals; however, these characteristics are small and are considered during manufacture of the crystals.

The operating instruction booklet issued with the test set has detailed explanations as to how the various crystal tests are performed. Also a temperature correction chart and calibration curves are included. When exacting tests are to be made, it will be necessary to use the charts in the instruction booklet.

Range Calibrator Set

A device used to simulate radar targets for accurate calibration of ranges is called a range calibrator. Such a test set usually operates on the principle of using a pulse from the radar under test to generate marker pulses that can be varied in their spacing and retransmitted to the radar receiver. Since the spacing or time between markers is known, the radar range can be calibrated within a few feet or yards. The UPM-11 is typical of these sets (fig. 7-42).

UPM-11

The TS-696, which is the main component of the UPM-11, is an electronic device which provides a means of calibrating accurately the radar range of any X-band radar system. The set may also be used with the narrow-beam pickup horn to collimate accurately the antenna axis of a radar system, which means alining the radar antenna optically (boresighting).

The TS-696 has provision for applying input in two ways—(1) by use of the pickup horn, and (2) by using coaxial cable attached to the directional coupler. The preliminary procedure and the interpretation of results will differ depending upon which method is used.

The test set contains a klystron local oscillator. The signal it produces mixes with the signal received into the AFC section from the radar under test to produce a 40 megacycle IF. (See fig. 7-43.) Part of the IF signal, called error voltage, is used as automatic frequency control (AFC) to keep the local oscillator tuned properly. The remainder is fed to a delay network which is in a temperature-controlled oven to assure constant delay. The output from the delay network is then fed to the signal section of the mixer assembly. From there it is fed through the TR tube to the pickup horn or RF cable where it is retransmitted to the radar as marker pulses or pips.

Each pulse received from the radar will cause ten or more usable marker pips to be generated. Notice the output of the delay line—each succeeding pip is lower in amplitude The multiple pips occur because part of the signal at the output end of the delay line i reflected to the input end and re-reflected t the output end. As each pip leaves the outpu end of the delay line, a portion of its energy i reflected through the delay line to produc another pip. The decrease in amplitude o succeeding pips is the result of energy los within the delay line with each reflection.

After about ten pips are produced, the amplitude is so low it is not usable. These te pips were all produced by only one pulse fro the radar. Each pulse starts the entire actio anew. Notice that the same antenna (picku horn or RF cable) is used both to receive th radar pulse and to retransmit the marker pips Notice also, that the distance (or time) between marker pips is determined by the physical length of the delay line.

A detailed discussion of circuit theory the UPM-11 is contained in the *Handbook* *Operation and Service Instructions*, T. O. N 16-30UPM11-1.

Spectrum Analyzers

During the modulation of a radiofrequency carrier wave by keying, by speech or music, or by pulses, the resulting wave contains many frequencies. The original carrier is present together with two groups of new frequencies called the sideband components. One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies when shown on a graph of voltage or power against frequency is called the spectrum of the wave.

A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radiofrequency range and in the microwave region.

In principle, the spectrum analyzer operat by tuning through the frequency region question using a narrow-band receiver. T output of the receiver is measured, usual by means of a cathode ray oscilloscope, a the plot on the screen is a graph of volta versus frequency.

The device is essentially a superheterody receiver with a very narrow-band intermediat frequency amplifier section. The local oscillator frequency is varied between two valu at a linear rate. The frequency-cont

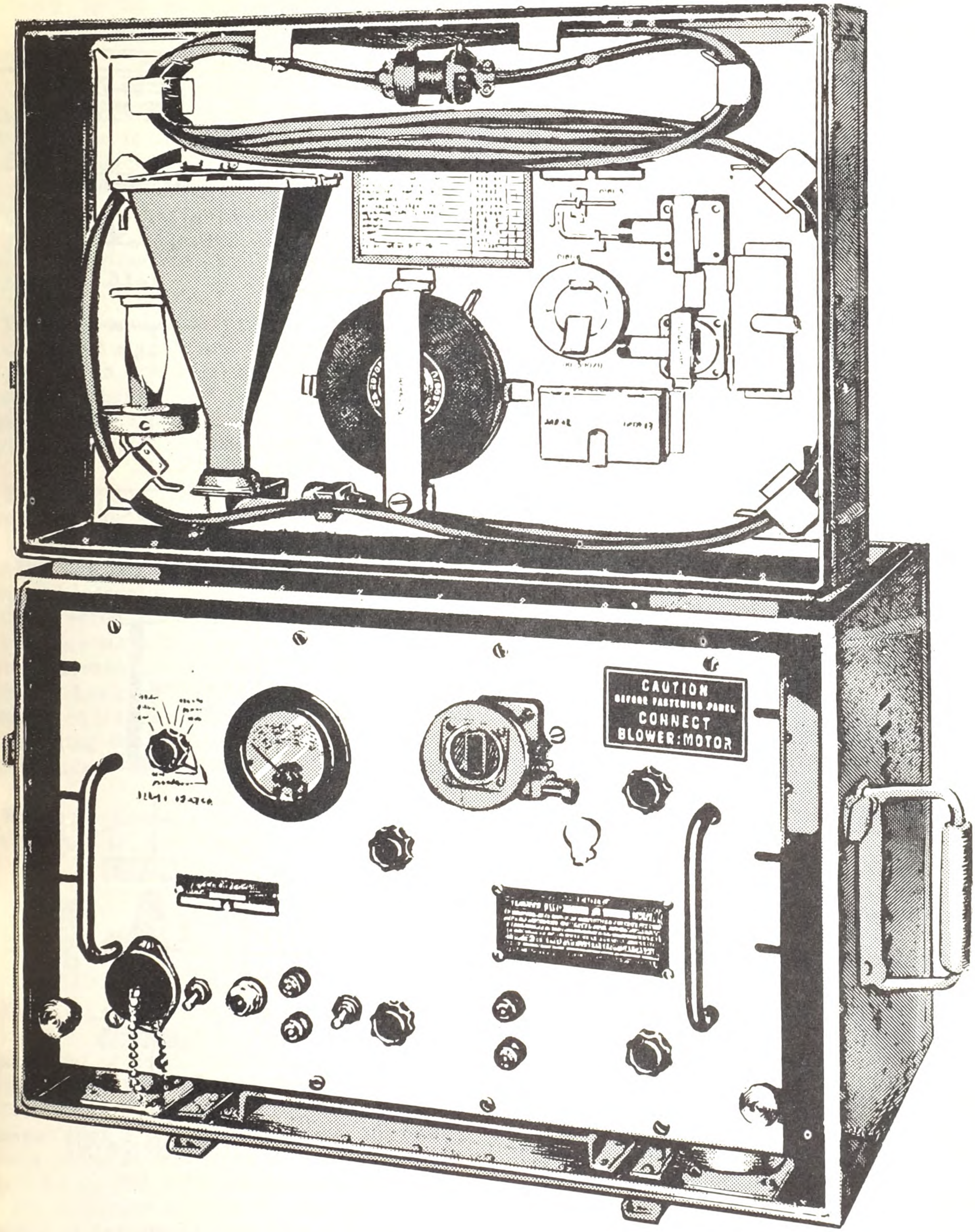


Figure 7-42.—Range calibrator set UPM-11.

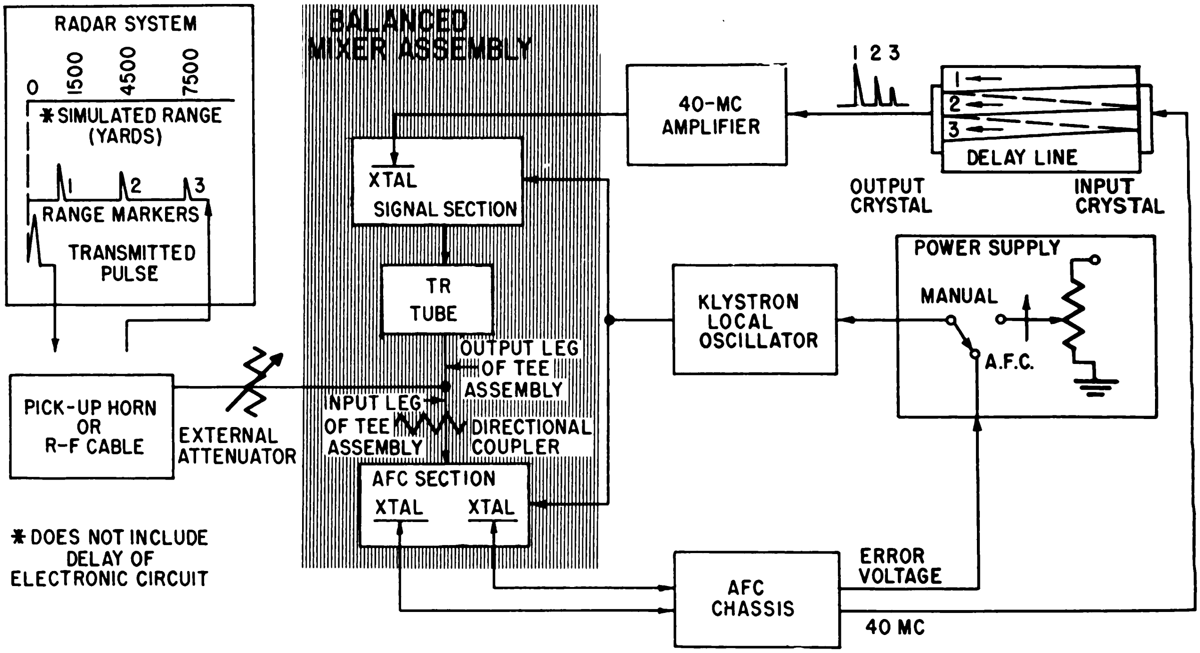


Figure 7-43.—TS-696 range calibrator, block diagram.

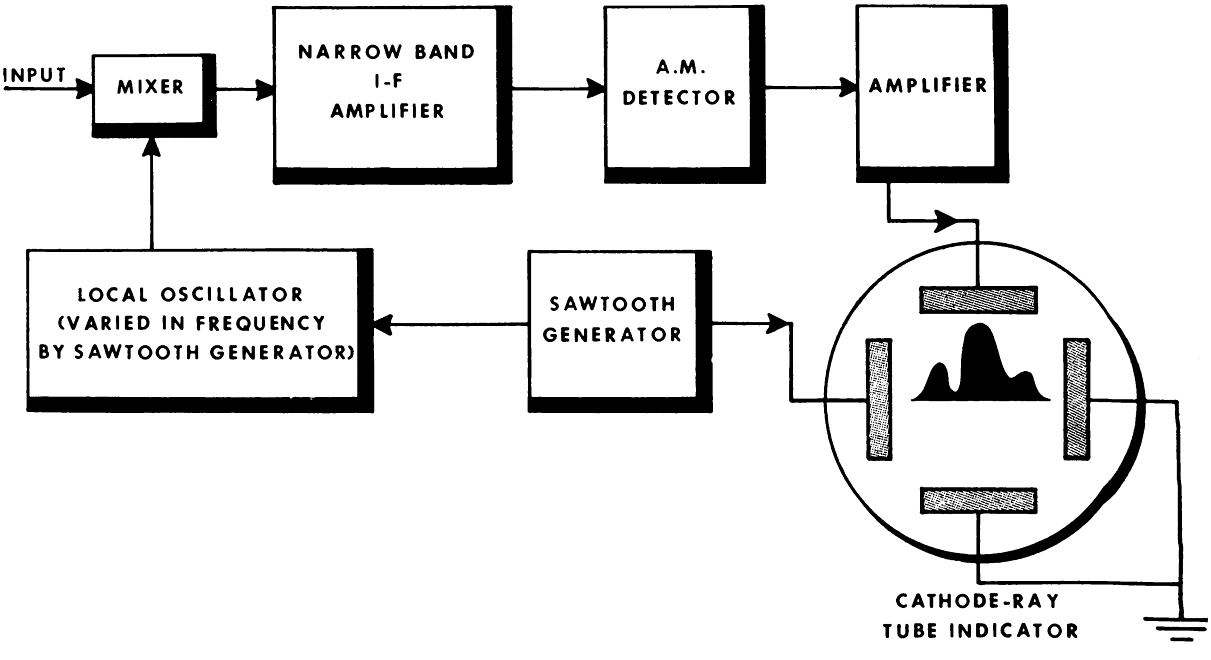

INPUT
MIXER
NARROW BAND I-F AMPLIFIER
A.M. DETECTOR
AMPLIFIER
LOCAL OSCILLATOR (VARIED IN FREQUENCY BY SAWTOOTH GENERATOR)
SAWTOOTH GENERATOR
CATHODE-RAY TUBE INDICATOR

Figure 7-44.—Block diagram of typical spectrum analyzer.

generator which governs the frequency of the local oscillator also produces the horizontal sweep voltage for the cathode ray tube deflection plates. (See fig. 7-44.) As a result, each position of the beam corresponds to a definite frequency value; and the display is a graph which the X-axis is interpreted in terms frequency.

The output of the detector in the recei is amplified and applied to the verti deflection plates so that the beam is deflected vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal to be analyzed is fed into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrow-band amplifier. The output of the IF amplifier is detected, amplified, and applied to the vertical deflecting plates.

Spectrum analyzers designed for analysis of microwave signals are equipped with klystron tubes in the local oscillator stage. In analyzers adapted for lower frequency RF signals, triode oscillators are used which are varied by means of reactance-tube modulators.

Spectrum analyzers are employed extensively in studying the output of pulse radar transmitter tubes such as the magnetron. In this kind of analysis, unwanted effects such as frequency modulation of the carrier can be easily detected. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation. A spectrum representing the ideal condition is shown in (A) of figure 7-45.

Examples of undesirable magnetron spectra are shown in (B) and (C) of figure 7-45. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

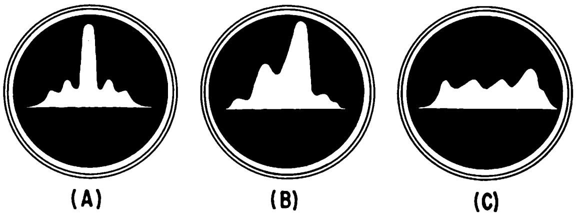

(A) (B) (C)

Figure 7-45.—Frequency spectra.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 7-45. In some analyzers this principle is used as a means of carrier frequency measurement. A sharply resonant circuit is provided in the receiver which acts as a trap to prevent an extremely narrow range of frequencies from appearing in the output of the IF amplifier. The result of its use is that a gap appears in the display and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. The frequency of the carrier is then read from the calibration of the trap.

NOTE: One type of spectrum analyzer presently in use in the fleet is the TS-148, which is the major unit of the UPM-33.

For an additional coverage of spectrum analyzers, consult *Basic Electronics*, NavPers 10087.

Combination Test Equipment

The numerous and complex operations required for servicing and maintaining radar requires, in some instances, numerous pieces of test equipment. Aircraft are restricted as to the number of test sets they can carry, so it follows that a test set combining the functions of several test sets is very practical. Such a set is the UPM-32. This combination test set performs most of the functions necessary for radar maintenance in its frequency range. The designation UPM-32 refers to the complete test set, including all accessories. TS-757 designates the test set without the accessories.

UPM-32

This test set (fig. 7-46) is portable and is designed primarily for use with radar systems operating in the frequency range of 8,500 to 10,500 megacycles. It functions as a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general-purpose synchroscope. The general applications of the test set are as follows:

1. Measurement of power, frequency, spectrum, and frequency pulling of conventional and multipulsed radar transmitters.

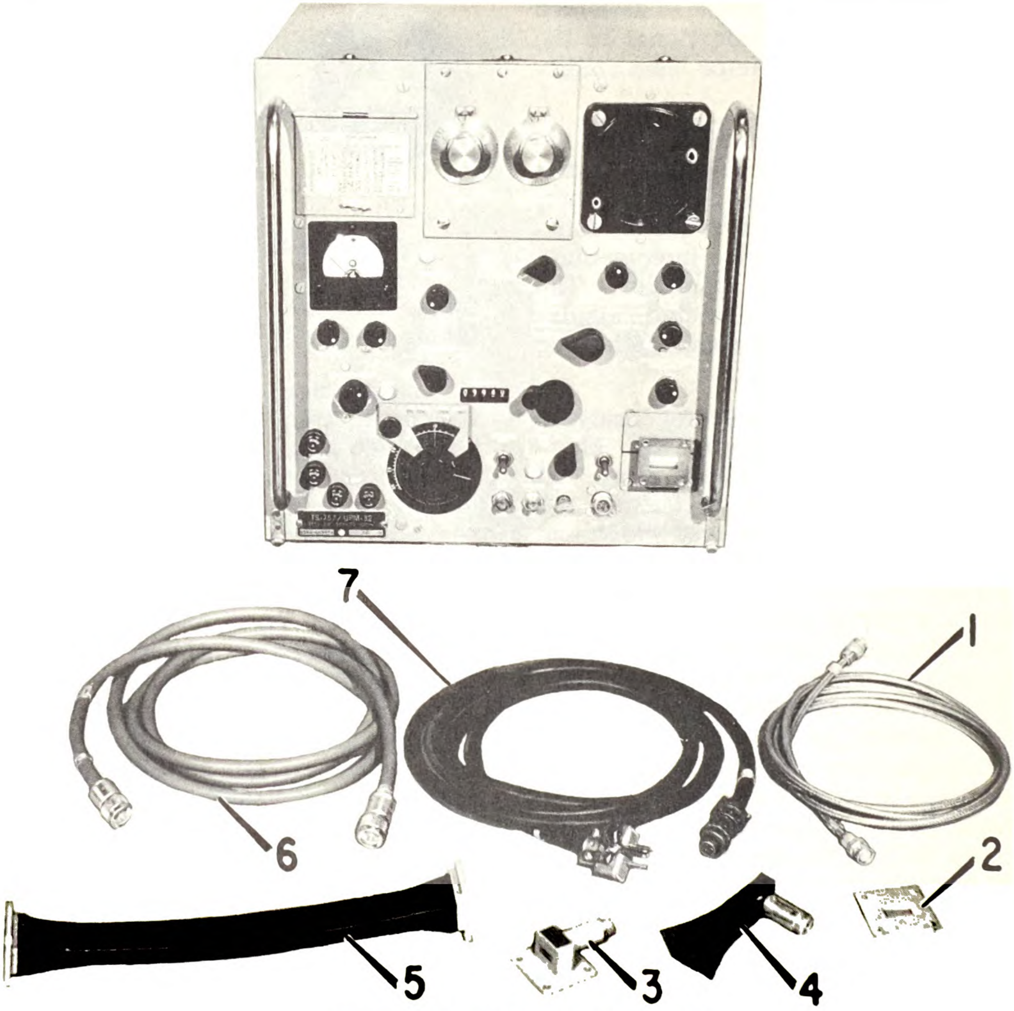


Figure 7-46.—Radar test set UPM-32.

1. Cable assembly.
2. Gaskets.
3. Adapter.
4. Test antenna.
5. Waveguide.
6. RF cable.
7. Power cable.

2. Measurement of sensitivity and bandwith of a radar receiver.

3. Measurement of the frequency and spectrum of a radar receiver's local oscillator.

4. Adjustment of a radar receiver's local oscillator.

5. Measurement of TR recovery time.

6. Observation of video signals.

7. Providing of pulsed, FM, or CW microwave signals.

The UPM-32 finds extensive use in large aircraft employing X-band radar. For example, it is used in the WV-2 aircraft for inflight checking of the APS-45 radar.

This test set is one of a series of test sets whose general functions are essentially the same except for frequency coverage. Other of the series are:

Test Set	Band	Frequencies
UPM-44	S	2,700 - 3,550 mc.
UPM-9	C	5,100 - 5,900 mc.
UPM-14	Ka	34,000 - 35,600 mc.

Once the radar technician becomes acquainted with the operation of these test sets he will find that maintenance of any radar se will be simpler.

Theory of operation of any of these tes sets is completely covered in the appropriat *Handbook of Service Instructions*, such a NavAer 16-30UPM32-502 for the UPM-32

QUIZ

1. What is the TS-505?
   a. Signal generator
   b. Oscilloscope
   c. Vacuum tube voltmeter
   d. Wavemeter

2. When plates are used in the CRT to deflect the beam, what type of deflection is used?
   a. Systematic
   b. Horizontal
   c. Electrostatic
   d. Electromagnetic

3. What is the purpose of a frequency meter?
   a. To measure the power output of a transmitter
   b. To be used as a frequency standard
   c. To measure the amplitude of RF
   d. To aline and troubleshoot tuned circuits

4. What is the primary purpose of a power absorption cone?
   a. To prevent interference with other radar
   b. To measure the frequency of a radar
   c. To provide a personnel safety device
   d. To prevent radiation from a radar antenna

5. What is the chief cause of test equipment failure?
   a. Carelessness
   b. Continuous operation
   c. Intermittent operation
   d. Incorrect voltages

6. Why do most test sets require periodic calibration?
   a. To insure optimum performance
   b. To prevent internal corrosion
   c. To check for signs of overheating
   d. To correct faults caused by carelessness

7. What does the emission-type tube tester indicate?
   a. Mutual conductance of a tube
   b. The ability of the plate in controlling plate current
   c. Relative value of an electron tube in terms of cathode emission
   d. The ability of the grid in controlling plate current

8. Which of the following designates a portable oscilloscope?
   a. TS-505
   b. USM-24
   c. URM-25
   d. TS-352

9. What is the purpose of a field strength meter?
   a. To provide a simple means to adjust the emitted or resonant frequency of transmitter
   b. To measure the relative power output of a transmitter
   c. To measure the field strength of a receiver
   d. To provide a simple means of measuring radar signals from a transmitter

10. What piece of test equipment can be used to measure the relative power output of radar?
    a. Wavemeter
    b. Signal generator
    c. Power absorption cone
    d. Echo box

11. When is the repair of test sets done at the squadron level?
    a. At any time
    b. When the test set has lost its calibration
    c. When calibration of the set is not involved
    d. When O & R is overloaded

12. What type of tube tester is the TV-7/U?
    a. Dynamic mutual conductance
    b. Emission-type tester
    c. Static tube tester
    d. Dynamic cathode emission type

13. What type of test equipment is the Model 670?
    a. RF coaxial line
    b. RF tube checker
    c. RF wattmeter
    d. RF load

14. Which instrument has no provision for emitting a signal?
    a. Heterodyne meter
    b. Frequency meter
    c. Signal generator
    d. Wavemeter

15. How many months of storage will be cause to remove the batteries from the TS-352A/U?
    a. 12 months
    b. 6 months
    c. 3 months
    d. 1 month

16. What is the indication on the TV-7/U when a tube is found to be shorted?
    a. The tube filament will not heat
    b. The SHORT lamp glows
    c. The tube tester power fuse blows
    d. The ON-OFF switch goes OFF

17. What power does the wattmeter indicate?
    a. The power applied to the input of the coaxial cable
    b. The power generated by the transmitter
    c. The power applied to the input connector of the dummy antenna
    d. The power applied to the output stage of the transmitter

18. What type of signal generator will often use an RC oscillator?
    a. UHF signal generator
    b. Video signal generator
    c. Audio signal generator
    d. RF signal generator

19. What is the primary purpose of an oscilloscope as used by electronics technicians?
    a. To calibrate test equipment
    b. To generate sawtooth waveforms
    c. To aline and troubleshoot electronic equipment
    d. To generate an electron beam

20. What is the characteristic input impedance of the Model 670?
    a. 50 ohms
    b. 72 ohms
    c. 300 ohms
    d. 37 ohms

21. What are the three main sections of an RF signal generator?
    a. Oscillator, modulator, and output control
    b. Power supply, modulator, and output control
    c. Modulator, output control, and attenuator
    d. Attenuator, power supply, and oscillator

22. How often must the TS-352A/U be inspected under extreme temperature conditions?
    a. 12 months
    b. 6 months
    c. 3 months
    d. 1 month

23. What is the purpose of the sweep circuit in an oscilloscope?
    a. To display the waveforms visually
    b. To provide sweep voltages so that the CRT produces a linear time base
    c. To provide a path to ground for the electrons
    d. To generate a calibrating voltage on the face of the CRT.

24. What is the frequency range of the Model 670 as a dummy load?
    a. 0 - 3,000 kilocycles
    b. 0 - 1,000 kilocycles
    c. 0 - 1,000 megacycles
    d. 0 - 3,000 megacycles

25. What type of oscillator is used in signal generators above 1,000 megacycles?
    a. Resistance-capacitance (RC)
    b. Inductance-capacitance (LC)
    c. Inductance-resistance (LR)
    d. Reflex klystron

26. What is the disadvantage of an ordinary voltmeter in comparison with a vacuum tube voltmeter?
    a. Will not measure the same voltages
    b. It is not as portable
    c. Will load the circuit under test
    d. Input impedance is too high

27. What is the purpose of the CRT?
    a. To display information
    b. To provide sweep voltages
    c. To troubleshoot and aline equipment
    d. To furnish a sweep voltage

28. What is the number of a typical standing wave ratio meter?
    a. Model 670
    b. MM-706
    c. USM-24
    d. TS-297

29. What is afterglow known as?
    a. Screen persistence
    b. The time of one trace
    c. Aquadag persistence
    d. Screen luminescence

30. What is the standing wave ratio of a transmission line?
    a. The ratio of maximum RF power to minimum AF power
    b. The ratio of maximum AF power to minimum AF power
    c. The ratio of maximum AF power to maximum RF power
    d. The ratio of maximum RF power to minimum RF power

31. The frequency of a cavity is increased by
    a. decreasing the size of the cavity
    b. moving the plunger out of the cavity
    c. increasing the size of the cavity
    d. leaving the cavity the same size and varying associated voltages

CHAPTER 8

AIRCRAFT ELECTRONICS MAINTENANCE

The purpose of this chapter is to set forth general maintenance procedures rather than the detailed procedures used with specific units and sets; however, for purposes of illustration, specific electronic units and sets are mentioned. Discussion will be given to (1) the types of inspections AT's are required to perform, (2) troubleshooting procedures used in aircraft as well as on the bench, and (3) repair information concerning printed and modular circuits, proper replacement of parts, AN type connectors, and cables and terminal blocks. Also general maintenance procedures for commutators, relays, and switches, and bearing care for rotating equipment will be included.

Inspections

DAILY AND PREFLIGHT INSPECTIONS

The daily inspection will be accomplished between the last flight of the day and the next scheduled flight. Basically, this inspection is a combination of requirements for checking equipment that requires daily verification of satisfactory functioning, plus requirements that prescribe searching for defects that become apparent after the aircraft is flown. It is intended that evidence of chafing, leaks, and similar conditions be discovered and corrected during this inspection. This is to prevent such relatively minor problems from developing to a state that would require major maintenance to remedy the deficiency. The inspection is, therefore, an important daily function that should be performed with care.

The preflight inspection will be accomplished immediately prior to each flight. This inspection consists of checking the aircraft for flight preparedness by performing visual examinations and operational tests to discover defects and maladjustments that, if not corrected, could cause accidents or aborted missions.

Standard naval procedure requires that a pilot give his aircraft a preflight inspection prior to takeoff. This is to assure that the aircraft is aerodynamically sound. Before the pilot makes his inspection the aircraft has already been inspected by technicians of various ratings to assure that it is operating properly. Your contribution to the successful performance of the mission is to ascertain proper operation of the electronic equipment. This means that the pilot and crewmen have at their command the electronic equipment so vital to any aircraft operation. When you finish your daily or preflight inspection, you know that all electronic equipment in the aircraft is operating properly.

Occasionally, because repairs or replacements cannot be made in time, or during the process of installing new equipment, it will be necessary for an aircraft to operate with some piece of equipment not operating, or not installed. When this occurs, the pilot must be informed. Do not leave the impression that all equipment is operating properly when you know that it is not. The pilot must know the status of his aircraft at all times in order that he may determine if it can perform the designated mission. Notification must be given if electronic equipment is not operating properly or is missing from the aircraft. Such information must be entered on the "yellow sheet," and also placed on the status boards in the Line and Maintenance offices. In addition, an excellent bit of insurance is to inform the pilot verbally of malfunctioning or missing equipment.

If an aircraft is to be flown with some electronic unit removed, it is sometimes necessary to add an equivalent amount of weight to maintain proper weight and balance. This is a command decision. When equipment has been removed, obtain permission from Maintenance before placing the aircraft in an "up" status. This permission is normally obtained by the electronics leading petty officer (leading PO); but, as the technician assigned to preflight a particular aircraft, it is your responsibility to ascertain whether permission has been given and to make sure that the pilot is notified.

Squadron policy will dictate the assignment of daily and preflight inspection crews and the scope of each man's job, but almost every AT will at some time be called upon to perform daily or preflight inspections. Many squadrons utilize the duty section for this job, particularly small plane squadrons, so the planes will be ready to fly at the start of the day's operation. You may be a qualified plane captain, and as such be assigned the responsibility of the entire inspection. When you sign the "yellow sheet" as plane captain, it indicates that you have checked to see that everything required by that sheet is properly signed off—oxygen, air bottles, structures check, electronics, hydraulics—just to mention a few. Any discrepancy should be brought to the attention of the responsible leading PO, and appropriate action taken before you sign the "yellow sheet."

Again, squadron policy will determine the extent of your electronics preflight, but it normally consists of operational and security checks. The operational check will vary between squadrons or units; but one thing that does not vary is the security check. There is invariably some means of securing electronic units in place, and often a means is provided for securing the plugs and cabling attached to the units. In connection with the operational check it is important that you check to see that all electronic power switches are in the OFF position after the check is completed. This prevents possible damage to your equipment by surge voltages when the aircraft is next turned up. Surge voltage can cause a variety of troubles, usually blown fuses; however, voltage regulator damage is not uncommon.

All electronic equipment in an aircraft is subjected to vibration and shock. Without adequate security some unit may shift from its proper place and become a weapon of destruction when it bounces around during maneuvers, or upon landing. The results could be disastrous. Even if the aircraft is not damaged, stretched or broken cabling always results, requiring many hours of work to repair. It is very difficult to explain such an occurrence if you signed the sheet for security, and impossible to justify having signed that sheet without checking. Do not become a victim of the idea that when an aircraft is just out of check that it is in perfect shape. Many people worked on the plane during the check, and extra special care should be given on the preflight.

It is usually desirable to correct electronic discrepancies as quickly as possible after a flight. Units operating large planes will probably have crews of maintenance personnel for this purpose. Even though the plane may not be scheduled for another flight in the immediate future you will find your leading PO unwilling to postpone correcting the "squawks." This shows good training on his part. Preparedness is always a keyword in the Navy. There are several reasons why discrepancies should be corrected as soon as feasible. For example, unscheduled planes may be called upon for immediate operation in connection with search and rescue, flyaway during storm conditions, or as replacement for another plane that developed last-minute trouble.

In small plane squadrons, "tail hooks" in particular, you must correct electronic discrepancies very fast because the flight schedule usually does not permit long periods for corrective maintenance.

PERIODIC INSPECTIONS

Intermediate Inspection

The intermediate inspection is performed between major inspections and is, basically, a limited overall examination of the condition of the aircraft. There are three intermediate inspections between major inspections, and they are termed first intermediate, second intermediate, and third intermediate. These inspections are more thorough than the daily or preflight, but do not include as many items as a major inspection. The *Handbook Inspection Requirements* for each aircraft will indicate how thorough the examination or test should be for each intermediate inspection.

Intermediate inspections will be accomplished at the following intervals:

1. The first intermediate inspection will become due at the expiration of 60 flying hours.
2. The second intermediate inspection will become due at the expiration of 60 flying hours after the first intermediate inspection (normally 120 hours after the preceding major inspection).
3. The third intermediate inspection will become due at the expiration of 60 flying hours after the second intermediate inspection (normally 180 hours after the preceding major inspection).

Calendar Intermediate

If an airplane does not accumulate 30 flying hours in the 60-day period following an intermediate or major inspection, then the next inspection due shall be accomplished. Normal flying time between inspections is 60 hours, and the plane will normally accumulate 60 hours flying time in less than 60 days; but if 50 percent of the required flying hours (30 hours) have not been accumulated in 60 days since the last inspection, then the next inspection due shall be accomplished.

Major Inspection

The major inspection is a thorough and searching inspection of the entire aircraft. It will be accomplished at the expiration of 60 flying hours after the third intermediate inspection (normally 240 flying hours after the preceding major inspection).

This is the most intensive inspection that will be made on the squadron level, and virtually everything in the aircraft will undergo a thorough check. Some items not required on the intermediate inspections will be performed on the major, such as inspecting motor brushes for cleanliness and wear, gearteeth and bearings for lubrication and excessive wear, and, in some cases, pressurization of a unit.

Calendar Major Inspection

If an aircraft has not accumulated 120 flying hours (50 percent of the 240 hours between major inspections) in 180 days since the last major inspection, then the next major inspection due shall be accomplished.

Inspection Crew Leader

Normally, on any of the periodic inspections, one AT will be designated as crew leader, and will sign the check sheet as such. His signature on the check sheet indicates that everything required of that particular inspection has been accomplished, even though he may have performed only a part of the inspection. Usually, more than one man will be assigned to "pull a check," and the crew leader must see that each man signs the check sheet for the portion of the work he accomplished, and also he must ascertain if that work was done properly. He must coordinate the efforts of the check-crew personnel from his shop, and, if necessary, coordinate his check with those from other shops. After the electronic equipment has been checked and reinstalled, the crew leader should perform an operational and security check before signing the inspection sheet. The responsibility for the completeness of the inspection rests with the crew leader.

The inspector from your shop will be assigned according to squadron or shop policy. His signature on the check sheet indicates that the aircraft is, in every respect, ready for flight electronically, and all paperwork concerned with the inspection has been completed. His signature does not relieve the crew leader of his responsibility for the completeness of the inspection.

ACCEPTANCE AND TRANSFER INSPECTIONS

An acceptance or transfer inspection is performed on an aircraft when a squadron transfers it or receives it. If the aircraft is to be delivered to another squadron or an overhaul activity, the transfer inspection is first performed to make sure all discrepancies are corrected. If an aircraft is to be received by a squadron, an acceptance inspection is performed to make sure all discrepancies are corrected before the squadron accepts the aircraft. Both the acceptance and transfer inspections are performed without regard to accumulated flight time or calendar time.

No pilot wants to fly an aircraft until he is assured that it measures up to required standards. The acceptance or transfer check will be thorough enough to determine if all discrepancies have been corrected, if the required field changes have been incorporated, and if proper entries have been made in the aircraft log.

INVENTORY

An inventory is held on an aircraft each time it is transferred from one activity to another. The transferring activity inventories it before releasing it, and the receiving activity inventories the aircraft before accepting it. In this manner, a running check is maintained to insure against loss of equipment in transit. The inventory is performed by referring to the Standard Inventory Log, or the Aircraft Inventory Record, which has a complete listing of all the items to be checked on the inventory.

Chapter 3 of this training course tells what items appear in these inventories, and the difference between the Standard Inventory Log and the Aircraft Inventory Record.

When practicable, the unit transferring an airplane and the unit receiving it will inventory the airplane simultaneously.

Troubleshooting

AIRCRAFT PROCEDURES

Much of your time will be spent troubleshooting the equipment in your squadron's aircraft. This is reason enough for you to become a proficient troubleshooter. Your job is to maintain a great number of units and systems, many of which are quite complex, and which might seem at a glance beyond your ability to maintain. However, the most complex job will usually become much simpler if it is first broken into successive steps. Any maintenance job which you are required to do should be performed in the following order:

1. Analyze the trouble.
2. Detect and isolate the fault.
3. Correct the fault and test your work.

In troubleshooting, as in most other things, there is no substitute for common sense. A mistake made by most beginners is to remove major units from the plane unnecessarily. When a "squawk" is handed you, first determine if the equipment in question is actually faulty. Very often a preliminary check of the system in the plane will disclose a faulty control box, frayed or broken wiring, and, in rare cases, improper operating procedure—especially with new equipment. Occasionally, you will find an absence of power to the unit to be the cause of the trouble.

If there is an absence of power, you can assume temporarily that the set may be all right, and start checking the power source. Usually the best place to start checking for power is at the bus which supplies it. By consulting the *Handbook of Maintenance Instructions* you can locate successive points along a wire at which to make your power checks. The first and most important step is to check the condition of fuses and circuit breakers. Their condition will determine your next move. If a circuit breaker is tripped or a fuse blown, power should be turned off immediately, because this indicates a circuit malfunction and power should not be reapplied until the malfunction is corrected. If a short, ground, or overload condition is not indicated, continue to take power readings at the check points. The most common faults which interrupt power through a circuit are broken wiring, loose terminal or plug connections, faulty relays, and faulty switches. Be alert for these conditions when checking the successive points along a circuit.

Frequently headsets or microphones are faulty. Their operation is sometimes intermittent. Assure yourself that the equipment in question is actually faulty before removing it from the aircraft.

As a means of localizing trouble, it will oftentimes be expedient to replace a minor unit or set (for example, a control box) with one known to be operating properly. Then if the system operates properly the fault is in the set or unit that was removed.

BENCH PROCEDURE

Visual Inspection

Again, common sense is the rule. The visible condition of a unit is usually the first thing to check in any process of troubleshooting. If certain parts are obviously not in proper condition, correct these faults before going any further in your tests. Such conditions include parts being burned, loose from mounting, disconnected, dented, or any other obviously improper condition.

Crude as it may seem, your nose can be a good pinpointing device for certain troubles. A part that overheats usually gives off an odor that is readily detectable, and can sometimes be located by the combined use of eyes and nose only. Of course, location of a burned part does not necessarily reveal the cause of the trouble. In determining the cause of the trouble it is usually necessary to refer to the *Handbook of Service Instructions*. These handbooks will be your constant reference when performing maintenance on electronic equipment.

The *Handbook of Service Instructions* (HSI) for a particular unit or set contains a detailed explanation of the theory of operation of each circuit in the unit, block diagrams, practical wiring diagrams, and schematic drawings of each circuit. It gives the location of test points and the readings that should be found on them, and it shows what voltage, resistance, and sometimes what waveshapes appear on each pin of every vacuum tube. The handbook also contains directions for troubleshooting and alinement, and indicates results to be obtained and tolerance limits. Few technicians are so thoroughly familiar with an electronic unit that they do not have to use the HSI when performing maintenance. Chapter 3 of this training course contains a detailed description of the information that is presented in the HSI's.

Signal Tracing

The following procedure is given for tracing signals in communication receivers and audio amplifiers; however, this general procedure, with modifications, can be applied to most electronic troubleshooting. In radar the frequencies will be higher, the methods of signal application will differ, and the output in the final stage will be video (viewed) on a scope, instead of audio (heard) from a speaker. You will find that the *Handbook of Service Instructions* will give detailed procedures for testing whatever unit or circuit needs testing.

Signal tracing is a very effective method for locating defective stages in many types of electronic sets. It is especially useful when servicing communication receivers, audio amplifiers, and other equipment which normally contain no built-in meters. In signal tracing, a signal voltage similar to that which is present under operating conditions is taken from a signal generator and is then applied to the input of the circuit in question. The signals which result from this application are then checked at various points in the stage, using test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any high impedance instrument which is appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit to which it is applied.)

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any abnormal effect can be localized.

The gain measurement can be used as an example of an important method in signal tracing. By this procedure, a defective stage can be found quickly in a radio receiver or audio amplifier. A signal generator, with the output attenuator calibrated in microvolts, and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device. These data are generally found in the *Handbook of Service Instructions* for the receiver under test.

The output meter may be connected across the voice coil of the receiver or across the primary of the output transformer. The output of the signal generator is applied to the grid circuit of the stage under test. The attenuator of the signal generator is then adjusted until the output meter reads an appropriate value which will serve as a reference figure. The output of the signal generator is then applied to the output of the stage under test (or to the grid of the next stage), and the attenuator is adjusted until the same reference value is again registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator applies a voltage of 400 microvolts to the grid of an IF amplifier. This voltage causes the output meter to indicate some value to be used as a reference. When the generator signal is applied to the following grid, the signal strength must be increased to 4,000 microvolts to cause the output meter to indicate the same reference value. The gain of the stage is $\frac{4{,}000}{400}$ or 10.

If similar measurements made in the remaining stages of the receiver reveal one in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by voltage measurement, by resistance measurement, or by simple replacement of parts until the defective one is found.

When making stage gain measurements in receivers, the value of the applied signals must be low enough to prevent the AVC system from functioning; otherwise, the measurements will not be accurate. In the *Handbooks of Service Instructions*, the recommended signal values are usually stated in terms of the reference value to be used at the output meter.

Voltage Checks

Voltage measurements are made at various points in the stage suspected of being at fault, and the observed voltage values are then compared with the normal voltage values given in the *Handbook of Service Instructions*. From this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage, and after previous checks have been made to partially localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Some electronic sets have built-in meters, or plugs for front panel application of meters. These meters usually work in conjunction with a selector switch, and will read values of voltage or current at designated points. A defective stage can very often be isolated in this manner. (See fig. 8-1.)

When the defective stage is isolated, it becomes a matter of point-to-point checking to isolate the fault within the stage itself. A voltmeter will pinpoint the trouble, but it often becomes necessary to use an ohmmeter to determine the exact cause of trouble, such as shorted capacitors, open resistors or transformers, or wire grounded to chassis.

Resistance Checks

This method is similar to voltage checking except that the power is removed from the set and resistance values are measured with an ohmmeter. The resistance values are then compared with the normal values given in the maintenance publications. This method, like voltage measurement, is most effectively used after the trouble has been isolated to a particular stage, since reliance on resistance measurement alone is too time-consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often quickly leads the technician to the cause of the trouble.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitor, using the high-resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is leakage present between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance will be greater in one direction than the other.

Should a capacitor indicate a short-circuit, one end of it must be disconnected from the circuit and another resistance reading be made to determine if the capacitor is actually at fault.

Unless your ohmmeter has a very high resistance scale you will not see a deflection of the meter when checking small capacitors. Even a scale of $R \times 10{,}000$ is not sufficient for very small ones; the smaller the capacity the less leakage across the plates, therefore more resistance.

When making resistance checks be sure to determine what circuits are connected to the points where the checks are made. The HSI will indicate what resistance should be found at various check points throughout the set, and will contain a complete schematic of the set as well as a circuit schematic of the stage under test. The schematics may set up conditions under which voltage and resistance measurements are to be made, such as positions of switches and control knobs, relays energized or deenergized, tube in socket, and so forth. These conditions will duplicate the conditions under which the measurements were first made. A typical condition might be: "Power switch OFF—all controls on control box fully CCW (counterclockwise)." It is important that these instructions be followed to obtain accurate values to compare with specified values. Otherwise incorrect values may be obtained.

Parts Replacement

Before replacing a defective part it is necessary to ascertain that such an operation may be performed by your unit or squadron. This is determined by the level of maintenance tha the squadron is allowed to perform. Increasing complexity and compactness of electroni equipment has caused a trend toward replacement of subassemblies rather than individua parts. This trend is caused by the necessity o

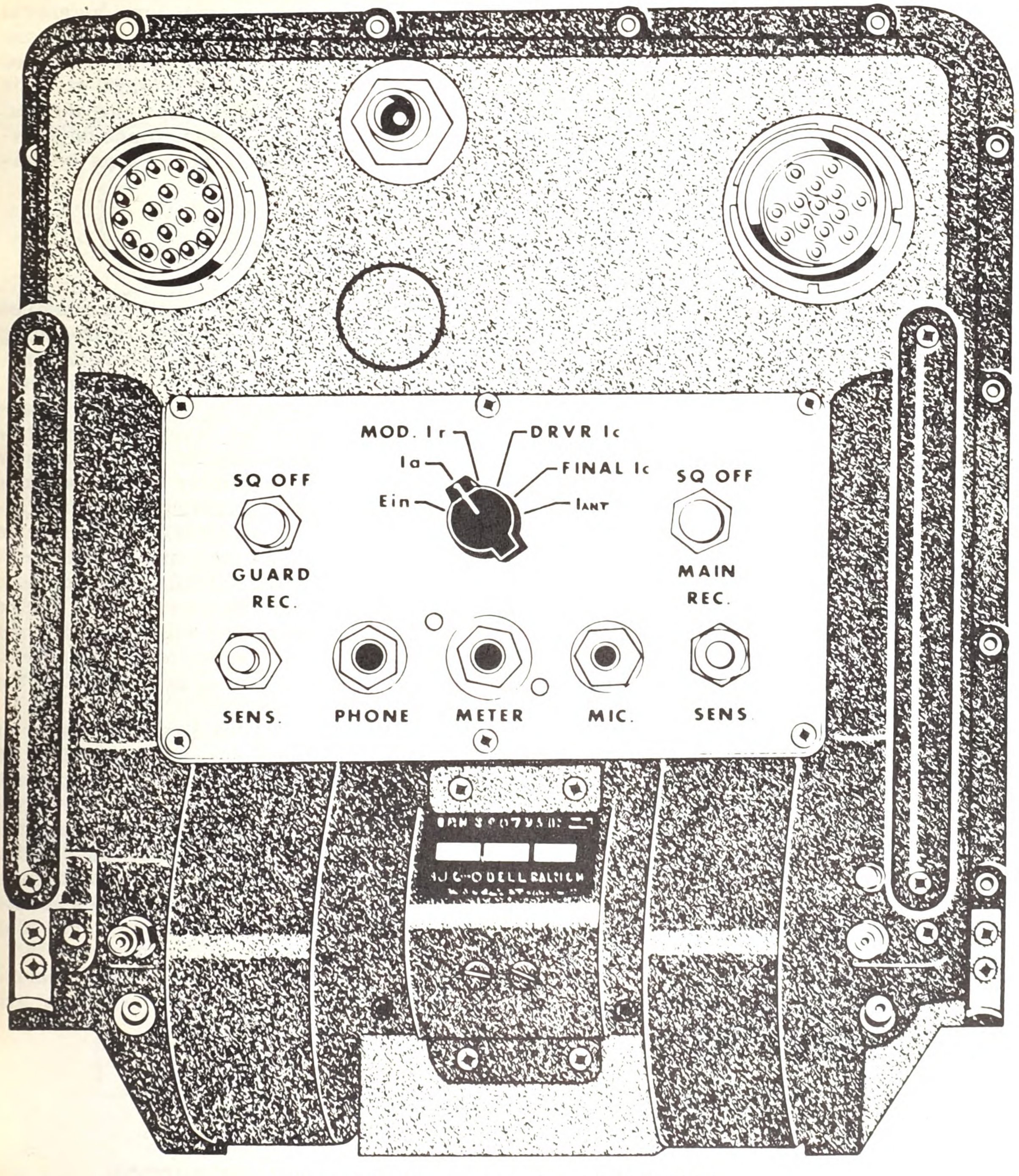


Figure 8-1.—Receiver-transmitter RT-178/ARC-27.

exact parts replacement, and the difficulty of working in small spaces where even the amount of solder used on a connection can be of importance. However, there are many parts that you will replace, and the rule is to replace a defective part with an exact duplicate.

There are certain publications that may be consulted to aid you in obtaining information (such as stock number and description) about a particular part. The publication that will most often be used when ordering parts is the *Section R* for the particular equipment under repair. Chapter 3 of this training course explains the use of the *Section R* lists and also the *Standard Aeronautical Electronics Material Section R,* NavAer 00-35QR4.

Another publication that will be used is the *Illustrated Parts Breakdown* for the equipment in question. It will show subassemblies in exploded views, give manufacturer's part numbers, and the Navy's stock number. The part number will describe the part in detail as to type of material used, value, tolerance, shape, and size. Familiarity with this book is a definite asset to the technician who must determine exactly what part to order.

When ordering electron tubes, the publication *Electron Tubes Used in Aeronautical Electronic Equipment Section R,* NavAer 00-35QR-7, will be used.

Should it become necessary to replace a part with a substitute, it behooves you, the technician responsible for proper operation of the equipment, to assure yourself the substitute part is a proper replacement. With resistors, for instance, several characteristics must be considered—ohmic value, wattage rating, tolerance, physical size, and type of construction. Capacitors involve consideration of physical size, capacity, tolerance, temperature coefficient and voltage rating. Plugs and connectors will almost invariably have to be exactly as prescribed since it is difficult to find items of this type that are interchangeable.

The Navy Training Course *Basic Electronics,* NavPers 10087, contains information on color codes for capacitors and resistors. Refer to this course for information on standard codes, specifications, physical shapes, methods for reading, and tolerances.

Figure 8-2 shows in chart form a general troubleshooting procedure. The directions given in blocks 1 through 5 are steps to be used in locating trouble, and the directions given in blocks 6 and 7 are steps in repairing the set. Steps 2, 3, 4, and 5 may sometimes be eliminated, but steps 6 and 7 will always be followed.

Checking Operation After Repair

No repair job is complete until the repaired unit or set is reinstalled and actually operating properly. You will naturally benchcheck a repaired set after the trouble is remedied, usually before the set is completely reassembled, and perform whatever alinement adjustments are necessary to assure proper operation. After reassembly of the set—replacement of dust and shielding covers, installation of set in outer case (and pressurization if necessary)—a final bench operational check should be performed. Oftentimes a shield or plate that has been installed will touch a bare wire or other contact and will render the set inoperative, or cause substandard operation. It is much better to discover such a fault at the bench than in the aircraft.

After the set is reinstalled in the aircraft and properly secured for flight, it must be given a final operational test. Do not assume that because the set operated properly on the bench it will do so in the aircraft. The most important test is an operational check under exact operating conditions. When the set performs properly in the aircraft and you are certain that it is securely mounted, you may sign the "squawk sheet." Your signature indicates that the electronic set should operate properly in allowing the pilot, crewmen, and aircraft to complete the mission.

Repair Information

The trend toward replaceable units has led to several new methods of construction of electronic equipment, amount which are printed and modular circuits. These circuits are designed for speed and economy of manufacture, and speed and ease of maintenance, as well as saving of space and weight. Maintenance, space, and weight are primary factors in aviation electronics.

CIRCUIT CONSTRUCTION

Printed Circuits

This type circuit is appearing more and more in electronic equipment. It has proven itself to be equal in operation to conventional type construction, with savings in space and weight, as well as economy of manufacture. A few

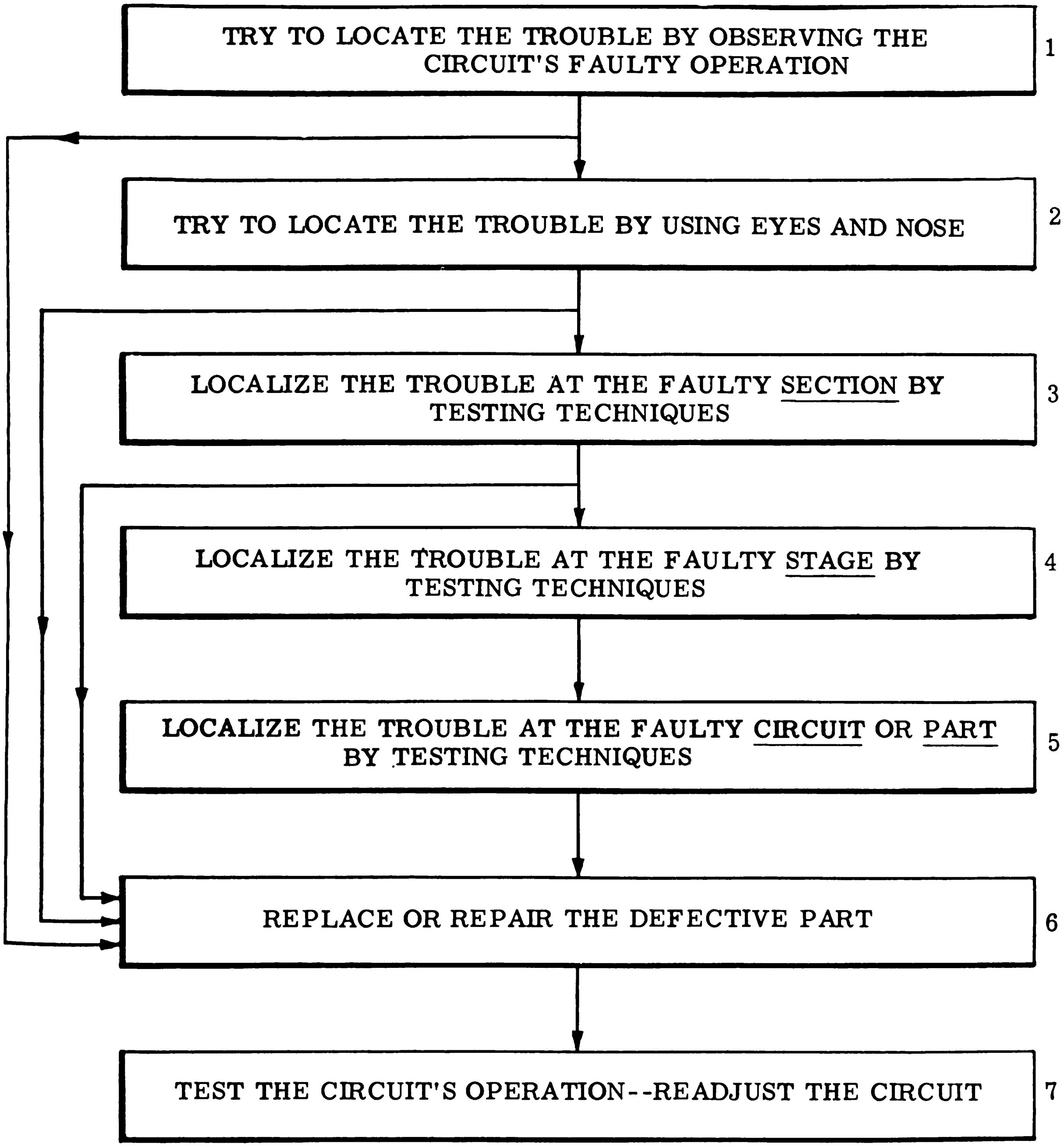

TRY TO LOCATE THE TROUBLE BY OBSERVING THE CIRCUIT'S FAULTY OPERATION
1
TRY TO LOCATE THE TROUBLE BY USING EYES AND NOSE
2
LOCALIZE THE TROUBLE AT THE FAULTY SECTION BY TESTING TECHNIQUES
3
LOCALIZE THE TROUBLE AT THE FAULTY STAGE BY TESTING TECHNIQUES
4
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
5
REPLACE OR REPAIR THE DEFECTIVE PART
6
TEST THE CIRCUIT'S OPERATION--READJUST THE CIRCUIT
7

Figure 8-2.—Troubleshooting procedure.

simple machine operations automatically produce circuits that formerly required a production line of workers performing the same jobs by hand.

Even printed components or parts are no longer unusual, the most common being resistors and capacitors. Printed components have not gained wide or extensive use as yet, therefore this discussion will be confined to printed circuits and methods of repairing them.

One method of manufacturing a printed circuit is the "photo-etching" process. A plastic or phenolic sheet with a thin layer of copper coating may be used. The copper coating is covered with a light-sensitive enamel, and a template of the circuit that will ultimately appear on the plastic sheet is placed over it. The entire sheet is then exposed to light. The area of the copper that is exposed reacts to the light. This area is then removed by an etching process. The exposure of the printed circuit is similar to a photographic exposure. The enamel on the unexposed circuit protects the unexposed copper from the etching bath that removes the exposed copper. After the etching bath, the enamel is removed from the printed circuit. This leaves the surfaces in a condition for soldering parts and connections.

Some manufacturers use machinery to mount standard parts like capacitors, resistors, and tube sockets, further speeding manufacture. Circuits thus produced operate as well as conventional circuits and are as easily repaired.

Should a printed circuit become broken, it is easily repaired by placing a short length of bare wire across the break and soldering both ends to the print; or, if the break is small, simply flow solder across it. (See fig. 8-3.) When performing these operations, do not apply too much heat, and do not permit solder to flow to other printed areas. The soldering gun, if properly used, is an excellent device for making these types of repairs since it affords constant and instantaneous control of the heat of the tip. If a conventional soldering iron must be used (one larger than a "pencil" iron), it is advisable to wrap a length of heavy copper wire around the tip of the iron and let one end of this wire extend as the soldering tip. This reduces the size of the tip, and therefore the heat transfer. This is illustrated in figure 8-4.

Many technicians think that printed circuits are very delicate and cannot be heated without danger of burning the baseboard or causing the conducting strips to separate. This attitude stems from lack of experience in soldering printed circuits. It is true that both of these things can happen, but with a little care and common sense, satisfactory repairs can be made to any printed circuit. In most cases, repairs can be made as easily as in conventional assemblies.

The phenolic boards used for printed circuits are similar to the phenolic strips used for conventional terminal strips and mounting boards. There has been no difficulty in soldering to the metal connectors on these terminal strips and mounting boards, so there should be none in soldering printed circuits. In rare cases where excessive heat causes separation of printed conductors from the phenolic board, repairs can be made by using jumper wires (See fig. 8-8.)

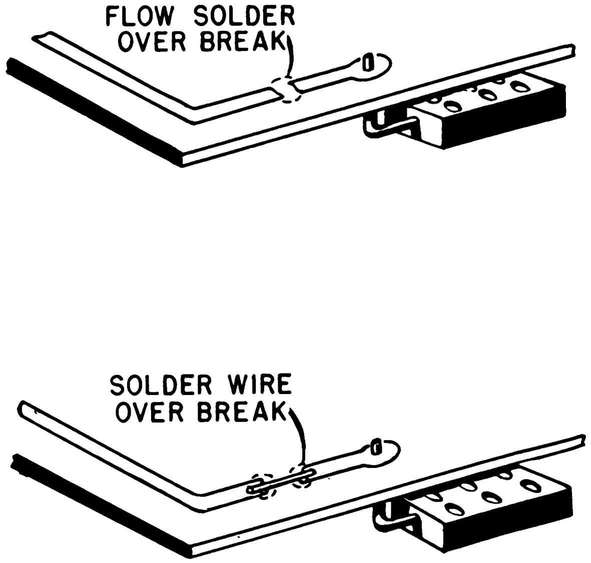


Figure 8-3.—Repairing breaks in foil.

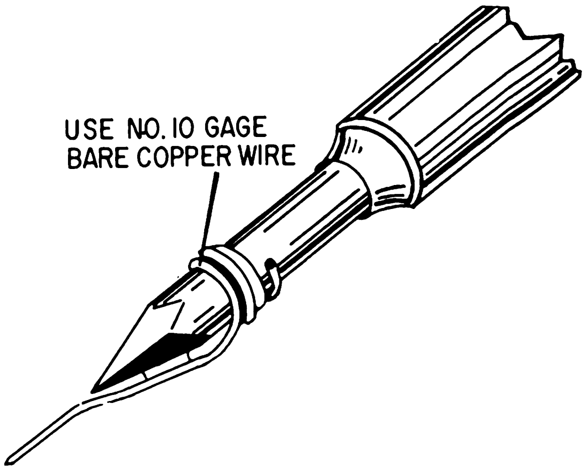


Figure 8-4.—Reducing tip heat.

Parts such as resistors and small capacitors are most conveniently removed if firs cut to free their leads. Much less heat is required to remove a part if the leads are free In cases where it is inconvenient to remove board for access to the wiring side, it is usuall possible to cut the leads of small resistors an capacitors so that a small portion of the lea is exposed. The new part can then be soldere to the old leads. This technique is shown i figure 8-5.

Should it become necessary to remove tube socket or any other part that require

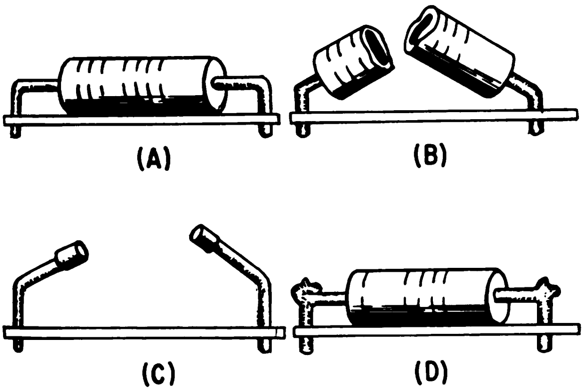


Figure 8-5.—Printed circuit resistor replacement. (A) Original resistor in place on board; (B) resistor after cutting with wire cutters; (C) wires exposed by crushing resistor ends with pliers; (D) new resistor soldered to stubs of old resistor wires.

simultaneous movement of several soldered connections (fig. 8-6), the following procedure should be used:

1. Remove all excess solder from each connection with a soldering iron or soldering gun.
2. While heating a connection, use a scribe or other pointed instrument to scrape away remaining solder. Caution: Do not "rock" or pry the part to loosen solder. "Rocking" can damage the printed circuit.
3. When all connections are free, simply lift the part from the board.

When a part is removed from a printed circuit board, the holes left in the board are cleaned of excess solder before the new part is installed. A small fiber glass brush is very useful for brushing the excess solder away while it is still soft. (See fig. 8-7.)

A metal probe, slotted at one end and pointed at the other, is useful in manipulating wires and lugs on parts to be removed from printed wiring boards. These devices, known as "soldering aids" and pictured in figure 8-7, are made of chrome plated steel to which solder does not readily adhere. They are also quite useful for handling wires to be soldered in conventional circuits.

Some printed circuit boards are coated with lacquer which must be removed before repairs can be made. Acetone or lacquer thinners are satisfactory solvents. New lacquer should be painted on the board after the repairs are completed.

If a piece of the printed circuit becomes raised from the board, clip off the raised section and replace it with a piece of copper wire. (See fig. 8-8.)

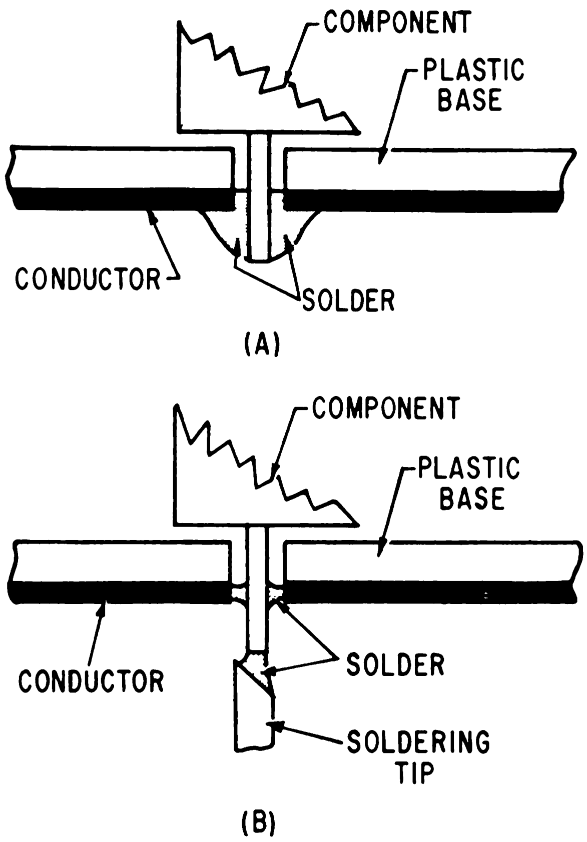


Figure 8-6.—Removing a part from printed board.

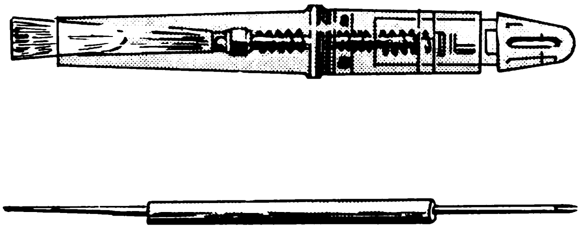


Figure 8-7.—Soldering aids.

Modular Construction

Some years ago the Navy launched a project for the purpose of finding ways of constructing electronic equipment so as to make maintenance easier and faster. From this project came, among other things, the module. A module is a stacked assembly of square flat ceramic wafers, each of which bears a printed circuit. This is illustrated in figure 8-9.

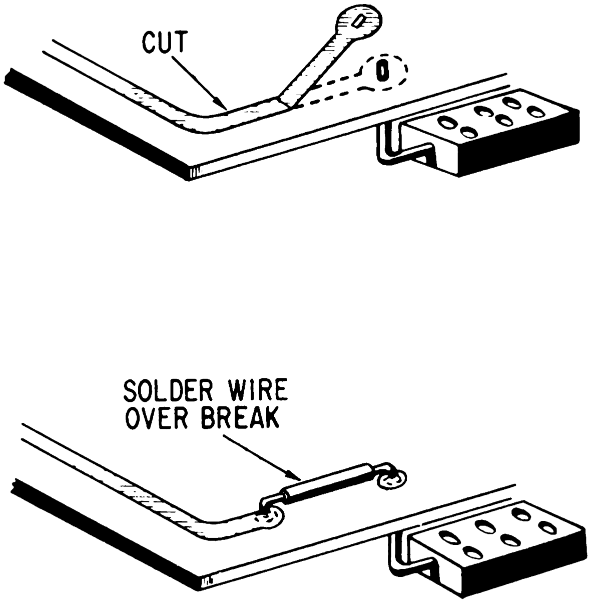


Figure 8-8.—Repairing raised section of foil.

These wafers can be arranged to form complete circuits, with stiff wires making connections in the slots around the edges of the wafers. (See fig. 8-10.)

The module can be wired into a printed circuit board, and as such is a complete circuit in itself. They are not intended to be repairable, and when a trouble exists the entire module is replaced. As yet, the module has not found wide use, but will very probably be used more and more in the future.

Potted Units

This type unit has been used for some time and speeds the process of troubleshooting considerably. A potted unit is a plug-in unit containing one or more circuits, hermetically sealed for moistureproofing. There are no movable parts in a potted unit, and it is filled with a sealing wax before the can is sealed. Each unit contains circuits, usually tuned circuits for special application; and by observing proper troubleshooting techniques, a faulty unit is easily located and replaced. Potted units are not repairable.

Potted units usually contain transformers or amplifier stages, such as d-c amplifiers.

Book Circuit Construction

One of the more recent and better types of construction for troubleshooting is the book. This type construction is used extensively in the navigation equipment ARN-21. (See fig. 8-11.)

Referring to figure 8-11, the numbers 1 through 8 show removable subassemblies called books. These books are readily removable and have numerous internal and external test points to facilitate troubleshooting. The books are built of standard parts that are easily replaceable. The test rack for the RT-220 has a plug extension that permits any book to be raised, making all parts accessible for checking and repairing. The book, unlike the module and potted unit, is not expendable but can be easily repaired, since all its parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are considered to be conventional.

REPLACEMENT OF PARTS

New designs and new techniques in the manufacture of electronic equipment requires that some of the old standards be revised, among which are methods of soldering specia parts, such as transistors and crystal diodes. These semiconductors cannot safely withstand the heat that even the pencil type soldering irons must produce to melt the solder that connects them in a circuit, unless a heat shunt is used.

NOTE: The soldering gun should not b used to solder transistorized equipment. Th strong electric field produced by the solderin gun may cause induced currents which may b great enough to damage the transistors. Eve the conventional soldering iron should b grounded to the chassis of transistorized equipment under repair.

Another change that new design dictates i the method of soldering wires or parts to terminal posts or connectors. The discussion tha follows sets forth the recommended solderin procedures as developed by the Navy Electronics Laboratory.

Soldering Semiconductors

Much new circuit design is based on the us of semiconductors. While some devices operat safely at high temperatures, the majority transistors and crystal diodes in use are particularly sensitive to temperature.

In most cases, transistors are mounted sockets. They should be removed from t sockets before any soldering of the sock

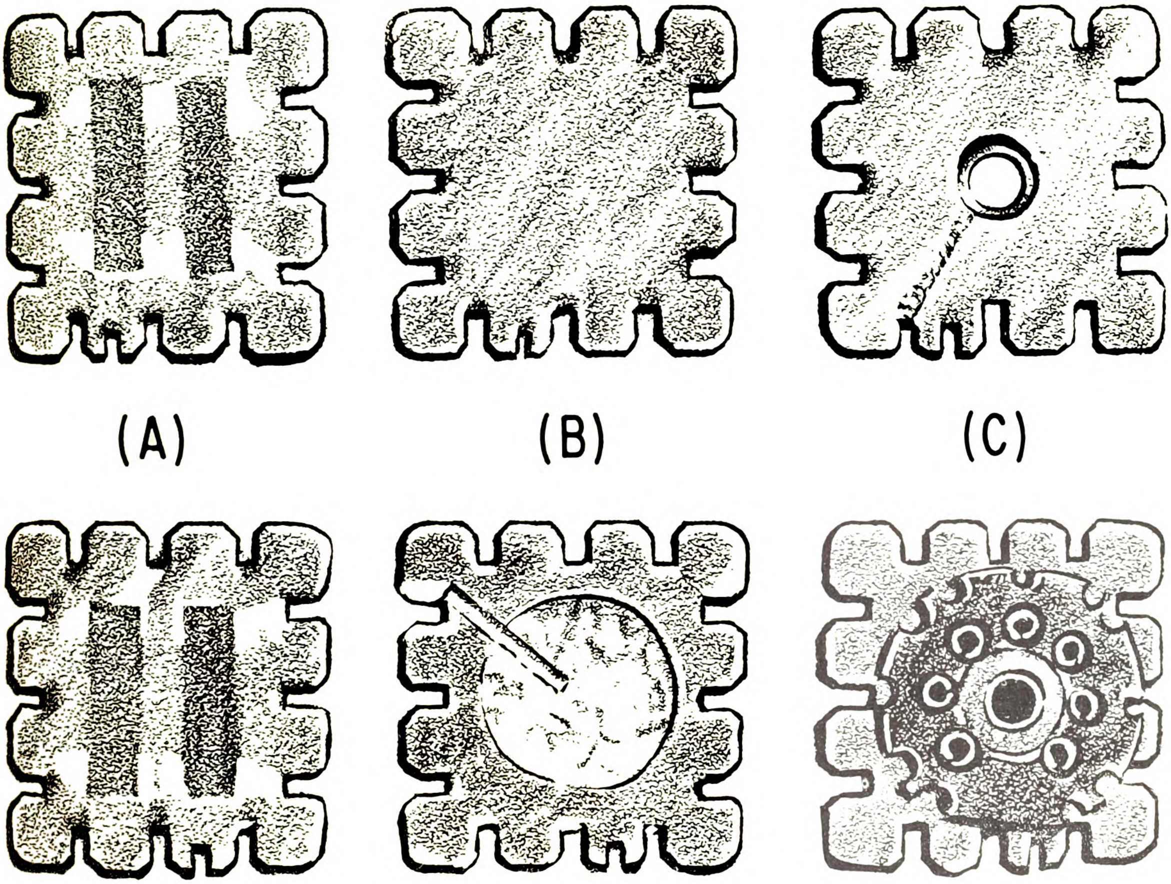


Figure 8-9.—Printed wafers. (A) Resistor wafer; (B) capacitor wafer; (C) tube socket wafer.

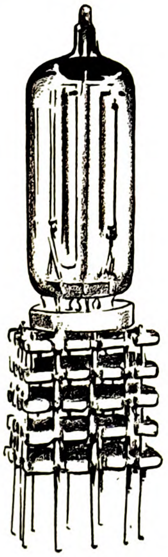


Figure 8-10.—Standard module.

terminals takes place. Some transistors and most crystal diodes in printed circuits are soldered directly in place. It is best, in these cases, to use a heat shunt, such as the one shown in figure 8-12. It should be clipped on the lead being soldered, between the joint and the transistor, diode, or resistor, to dissipate the excess heat. Other tools that may be used as heat shunts are surgical hemostats and pointed nose pliers. (Hemostats may be obtained from the sick bay or hospital when they are no longer usable for surgical purposes, and you will find them an invaluable addition to your tool box.)

Strength of Soldered Connections

The various radio and electronics handbooks emphasize the necessity of tightly wrapping wires around terminals before soldering. This

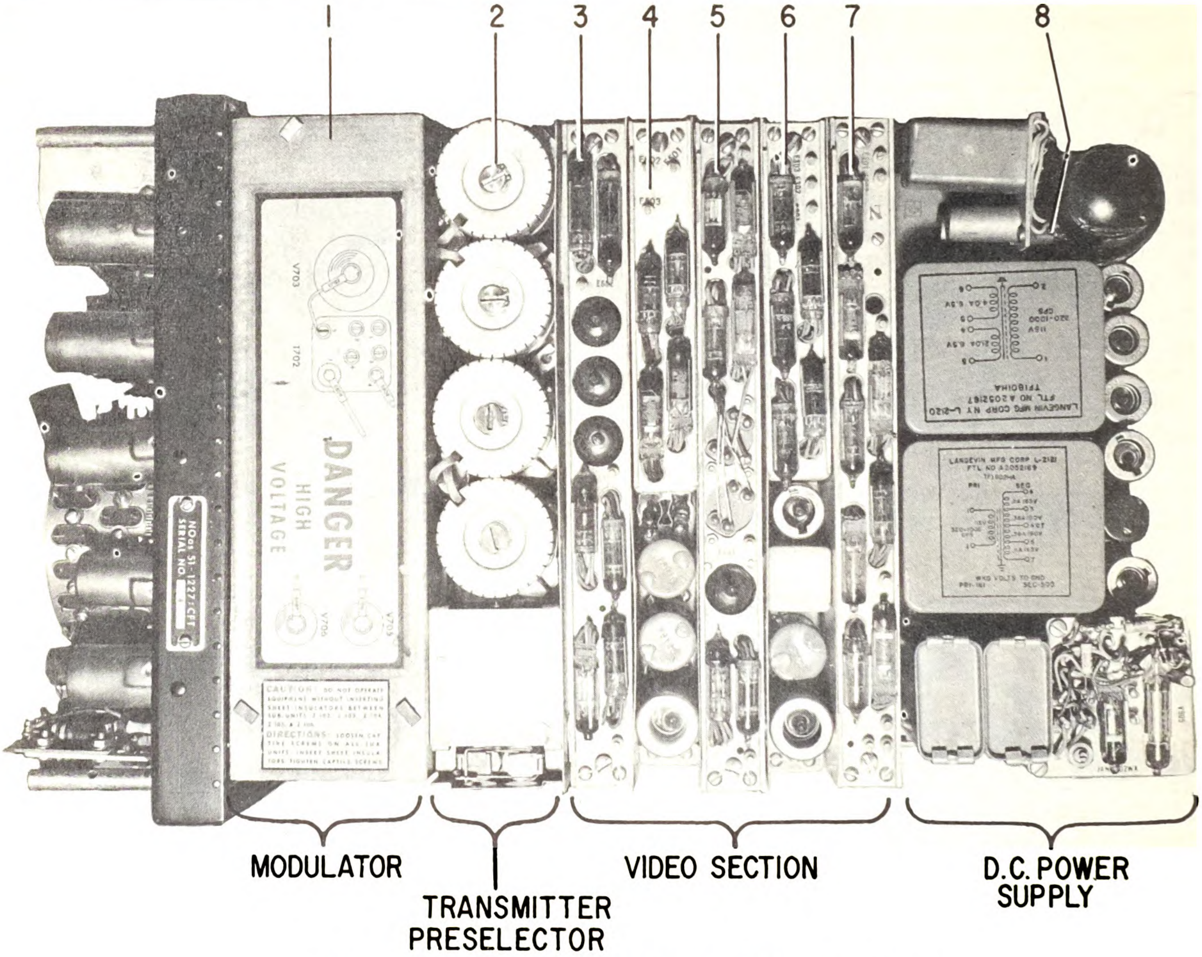


Figure 8-11.—RT-220/ARN-21, showing book construction.

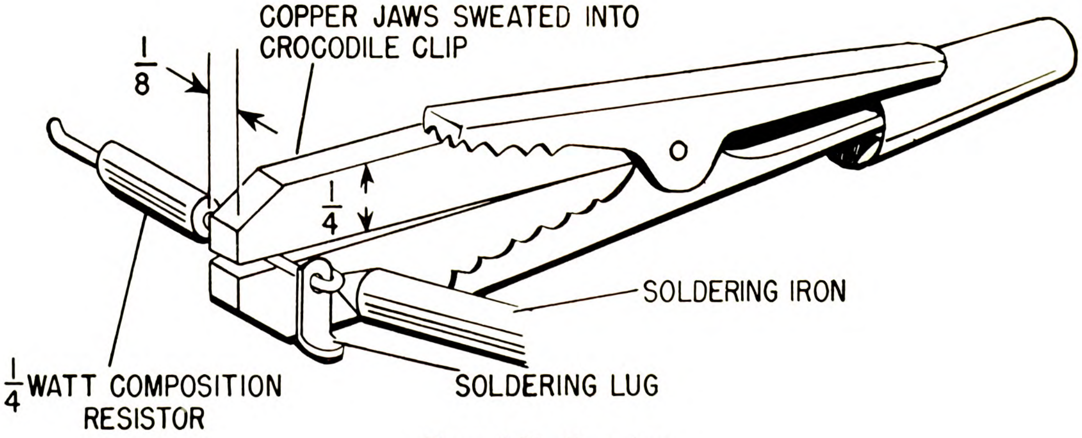


Figure 8-12.—Heat shunt.

practice is required by Federal specifications, but efforts are now being made to revise the requirements in the light of recent investigations on solder strength.

The Navy Electronics Laboratory tested many standard capacitors and resistors soldered to terminals of various types. These were subjected to vibrations far in excess of those encountered in military ships, aircraft, and armored vehicles. Although the connections were deliberately made with no wrapping of wires around terminals, but instead with reliance for support placed in the soldered joint, there were no failures. (See fig. 8-13.) Similar tests, with equally encouraging results, have been conducted by a number of commercial electronics firms.

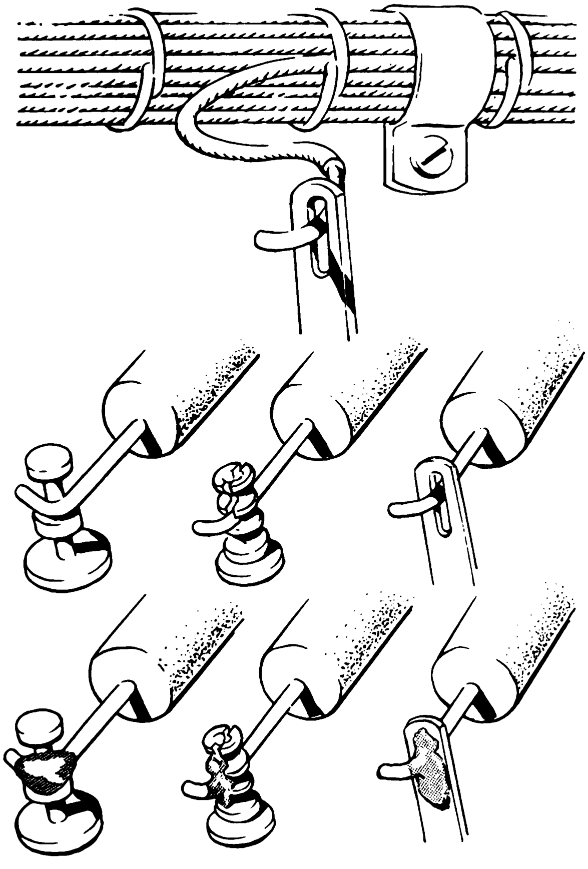


Figure 8-13.—Soldering method recommended by Navy Electronics Laboratory.

The advantages to be gained from using connections that depend on solder for strength are: ease of assembly; ease of removal for test or replacement; less chance of poor soldering (lack of solder in joints and/or rosin joints) since faulty soldering is more readily detected by visual or electrical inspection methods than when the wire is wrapped before soldering; less heat required in soldering and unsoldering; and less strain on parts since their leads do not get as much pulling and twisting as with the conventional wrapping technique.

Recommendations have been made that Federal specifications be revised to require that small parts be connected with no more than one-half turn of wire around the terminal, followed by a simple and neat soldering job.

Temperature of Soldering Irons

All high quality irons operate in the temperature range of 500° to 600° F. Even the little 25-watt midget irons produce this temperature. The important difference in iron sizes is not temperature, but the capacity of the iron to generate and maintain a satisfactory soldering temperature while giving up heat to the joint to be soldered. Naturally you would not try to solder a heavy metal box with the 25-watt iron, but you would find that iron quite suitable for replacing a half-watt resistor in a printed circuit. A 150-watt iron would be satisfactory for use on a printed circuit, provided proper soldering techniques are used. One advantage of using a small iron for small work is that it is light and easy to handle and has a small tip that is easily inserted into close places. Also, even though its temperature is high, it does not have the capacity to transfer large quantities of heat.

Some irons have built-in thermostats. Others are provided with thermostatically controlled stands. These devices control the temperature of the soldering iron, but are a source of trouble. A well-designed iron is self-regulating by virtue of the fact that the resistance of its element increases with rising temperature, thus limiting the flow of current. For critical work, it is convenient to have a variable transformer for fine adjustment of heat, but for general-purpose work, no temperature regulation is needed.

One type of iron is equipped with several different tips that range from 1/4 inch to 1/2 inch in size (diameter) and are of various shapes. This feature makes it adaptable to a variety of jobs. Unlike most tips which are held in place by setscrews, these tips are threaded and screw into the barrel. This feature provides excellent contact with the heating element, thus improving heat transfer efficiency. A pad of "antifreeze" compound is supplied with each iron. This compound is applied to the threads each time a tip is installed in the iron, thereby enabling the tip to be easily removed when another is to be inserted.

A special feature of this iron is the soldering pot that screws in like a tip and holds about a thimbleful of solder. It is useful for tinning the ends of large numbers of wires.

Soldering Gun

Because it heats fast and cools fast, the soldering gun has gained great popularity in recent years. It is especially well adapted to maintenance and troubleshooting work where only a small part of the technician's time is spent actually soldering. A continually hot iron oxidizes rapidly and is difficult to keep clean.

A transformer in the gun supplies about 1 volt at high current to a loop of copper that serves as the tip. It heats to soldering temperature in 3 to 5 seconds, but will heat to as high as 1,000° F. if left on longer than 30 seconds. Because it operates for short periods of time, very little oxidation is allowed to form; thus it is one of the easiest soldering tools to keep well tinned. On the other hand, this tip is made of pure copper with no plating, so pitting can easily occur as a result of the dissolving action of the solder. Offsetting this disadvantage, however, is the low cost of replacement tips—about 13 cents.

If delicate wires or printed circuits are to be soldered with a gun, it should be remembered that overheating can easily occur. With practice, heat can be accurately controlled by pulsing the gun on and off with its trigger. For most jobs, even the LOW position of the trigger will overheat the tip after 10 seconds. The HIGH position is only for fast heating and for soldering to especially large terminals. Incidentally, it is permissible to use soldering guns as well as regular soldering irons on the 400-cycle supply. In the case of guns, the heating time will increase and the maximum temperature will be somewhat lower, but no harm will result to the gun, and satisfactory soldering temperatures can be obtained.

Resistance Soldering

A time-controlled resistance soldering set, shown in figure 8-14, is now available through normal supply. The set consists of a transformer that supplies 3 to 6 volts at high current to stainless steel or carbon tips. The transformer is turned ON by a foot switch and OFF by an electronic timer. The timer can be adjusted for as long as 3 seconds soldering time. This set is especially useful for soldering cables to AN plugs and similar connectors—even the smallest types available.

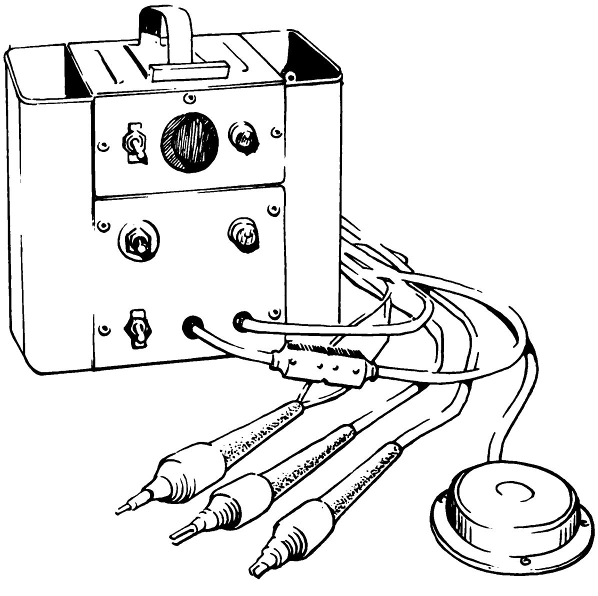


Figure 8-14.—Resistance soldering unit.

In use, the double-tip probes of the soldering unit are adjusted to straddle the connector cup to be soldered. One pulse of current heats it for tinning and, after the wire is inserted, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, burning of wire insulation and melting of connector inserts is greatly minimized.

The greatest difficulty with this device is keeping the probe tips free of rosin and corrosion. A cleaning block is mounted on the transformer case. Some technicians prefer fine sandpaper for cleaning the double tips. Caution: Do not use steel wool. It is dangerous when used around electronic equipment.

Replacement of Wiring

Wiring in aircraft normally runs from point to point, or plug to plug, without interruption (no splices). However, there are methods of splicing wires in aircraft that are acceptable as permanent splices. The *Handbook of Installation Practices for Aircraft Electric And Electronic Wiring*, NavAer 01-1A-505, gives full details on splicing and many other factors concerning wiring practices.

Wiring in aircraft is identified by a system of numbers and letters stamped on each wire. The *Handbook of Service Instructions* and the *Handbook of Maintenance Instructions* give the number of each wire involved in cabling of electronic equipment. Should it become necessary to trace and repair a wire in the aircraft, refer to these handbooks to determine the routing of the wire involved.

The handbook on wiring practice also gives excellent detailed procedure on installing a coaxial plug or fitting. This is a job that must be performed in the prescribed manner in order to prevent failure or substandard operation.

Wattage Ratings of Replacement Resistors

When a resistor must be replaced, one of the important considerations in selecting the replacement is the wattage value. In general, the wattage rating is a measure of the ability of the resistor to dissipate heat, and the value is related to the physical size of the resistor.

The selection of a safe wattage value is based on a consideration of the working conditions of the resistor in the circuit. Consider as an example, the replacement of an 850-ohm resistor with one of equal ohmic value but which has a tolerance of ± 20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as 680 ohms. Taking the lesser value as the more unfavorable from a heat-dissipating standpoint, the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$W = 2.35$ watts, approximately.

A resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered, to allow sufficient margin of safety. In the example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, it is sometimes necessary to combine resistors in series or in parallel to obtain a desired resistance value. When this is done, care should be taken to avoid a voltage distribution (or current distribution) which causes any low-wattage resistor in the combination to dissipate an excessive amount of heat. For example, suppose two 10-watt resistors of 1-ohm value were combined in series with a 2-watt resistor of 10 ohms. The total wattage dissipated when the series combination is connected across 12 volts is 12 watts. But the power dissipated by the 10-ohm, 2-watt resistor is 10 watts, a value far in excess of its capabilities. It is necessary to consider each resistor in the combination and select a wattage value based on the voltage developed across the individual unit.

AN ELECTRICAL CONNECTORS

Service, Inspection, and Maintenance

AN connectors are inspected when the major units that they connect are inspected. During this inspection the mating parts of the connectors are separated and the contacts examined for corrosion. If corrosion is present, the surfaces are cleaned with a brush or clean rag. The cleaning is finished with a noncorrosive solvent. The coupling ring is inspected for battered threads, and should be replaced if the threads are not in good condition. When attaching or detaching the connector, care should be taken to avoid damaging the coupling or bending the coupling ring.

If the connector does not contain the moistureproofing compound Thiokol, the conductors should be inspected where they are soldered to the pin contacts. Short circuits are often caused by a frayed strand of one conductor touching the solder cup of another conductor within the plug. If this is the case, the frayed strand may be clipped. Check to see that all soldered connections are adequate and that no cold solder joints exist.

AN connectors do not require lubrication except for the coupling ring threads. Occasionally, they should be given a light coat of antiseize compound to insure smooth operation.

Moistureproofing Electrical Connectors

At times operating conditions demand that ordinary electrical connectors be given a moistureproofing treatment. The basis of moistureproofing is the application of a sealing compound.

Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by

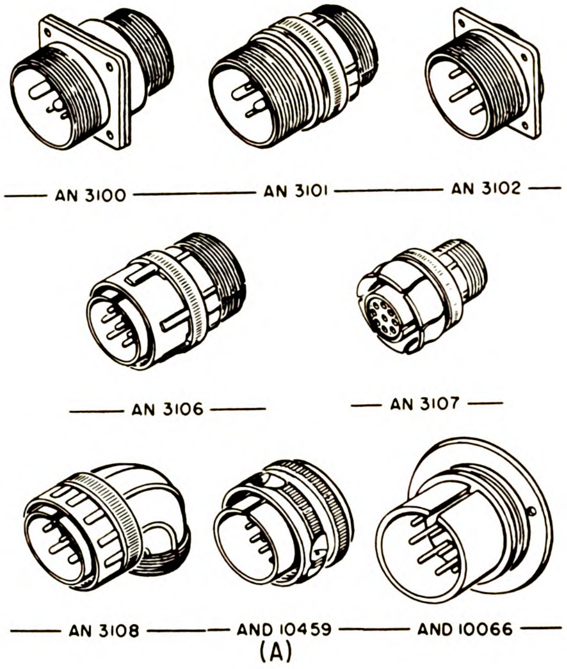


Figure 8-15.—(A) AN connector shells.

vibration and lateral pressure, both of which fatigue the wire at the solder cup.

The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved dielectric characteristics, it reduces the possibility of arc-over between pins at the back of electric connectors.

The sealant is provided in kit form through the normal supply channels. Sealing (or potting, as it is called) is not required on environment-proof E connectors or connectors located in areas where the temperature exceeds 200° F. The sealing compound deteriorates after long exposure to ambient temperatures above 200° F.

The detailed instructions for performing sealing operations may be obtained from the current Electronic Material Change covering this subject. A summary of the procedures involved in sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and by cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now, repeat the cleaning; and separate the wires evenly.

In preparing a new connector, solder wiring to the connector pins as required for the intended use and, in addition, the spare wires as just described. Next, remove the excess rosin, clean, and spread the wire.

2. Thoroughly mix the accelerator and base compound (fig. 8-16). The ratio of the amount of accelerator-to-base compound is critical; therefore, the entire quantity of accelerator furnished must be added to the base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold made of masking or cellophane tape or equivalent. This will retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the

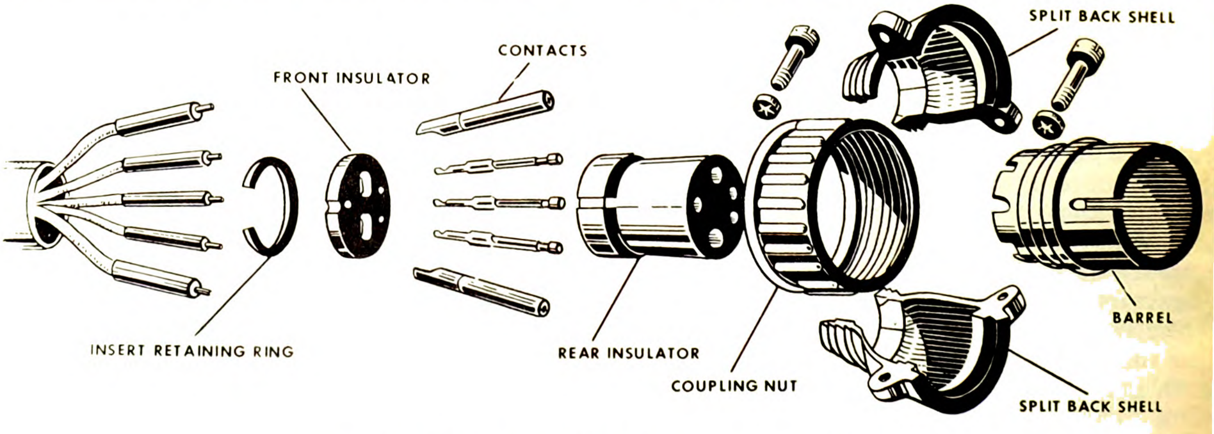


Figure 8-15.—(B) Exploded view of AN connector shell.

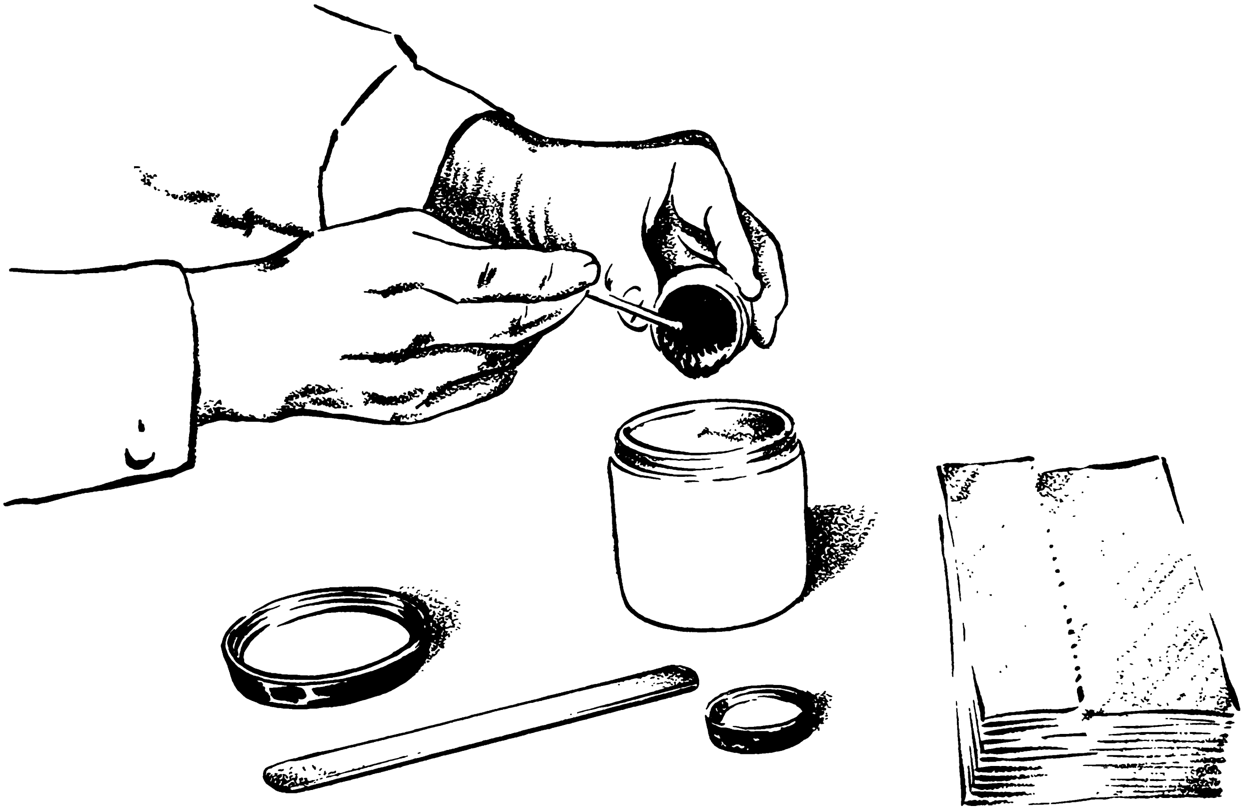


Figure 8-16.—Combining accelerator with base compound.

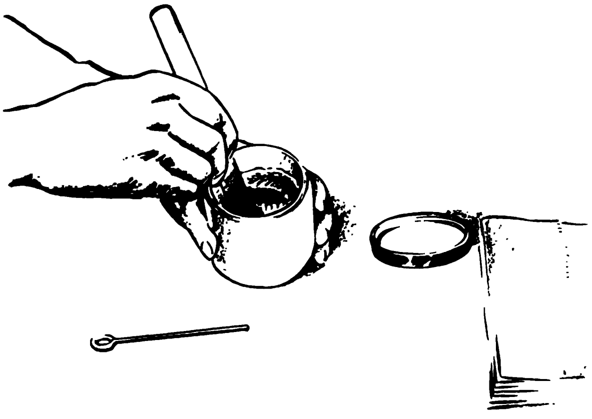


Figure 8-16.—Combining accelerator with base compound—Continued.

inner surfaces to prevent the compound from adhering to it.

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover 3/8 inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Due to the aging of these rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to provide for two eventualities: to allow for growth requiring additional circuits to be included in the connector, or to reduce the need of repairing a single wire which may have failed within the

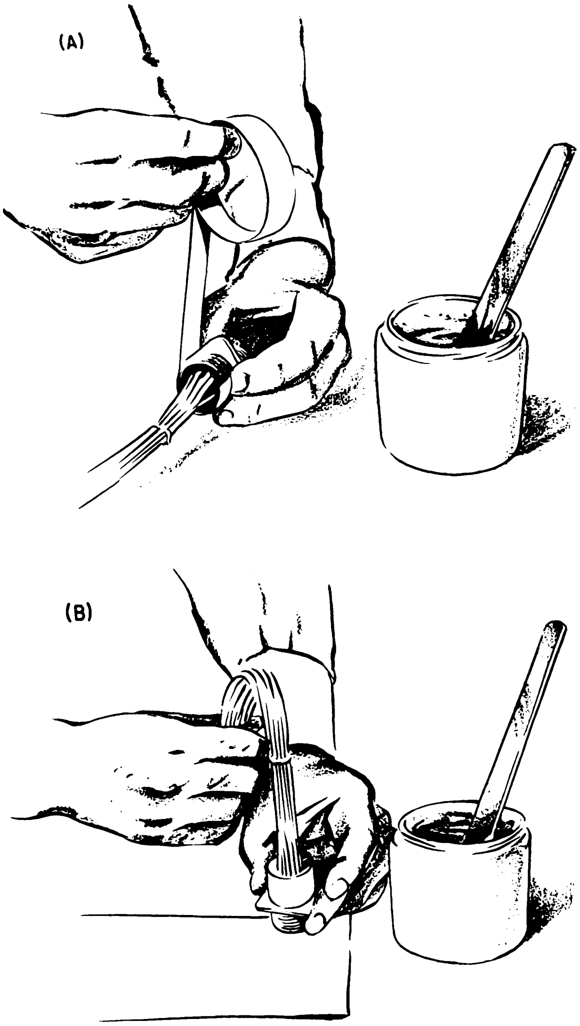


Figure 8-17.—(A) Making mold from masking tape; (B) finished potted plug.

connectors by making a splice to one of the spare wires.

CABLES AND TERMINALS

Cables

An important part of aircraft electrical maintenance is determining the correct wire or cable for a given job. For purposes of electric installations in aircraft a WIRE is defined as a stranded conductor, covered with an insulating material. The term CABLE, as used in aircraft electrical installations, includes the following: two or more insulated conductors contained in the same jacket (multiconductor cable); two or more insulated conductors twisted together (twisted pair); one or more insulated conductors covered with a metallic braided shield (shielded cable); a single insulated center conductor with a metallic braided outer conductor (RF cable).

For wire replacement work, the *Aircraft Maintenance Manuals* should first be consulted since they normally list the wire used in a given aircraft. When this information cannot be obtained from the manual, the repairman must select the correct size and type of wire needed. The factors used in determining correct wire size are explained in *Basic Electricity*, NavPers 10086. This information plus that given in Military Specification MIL-W-5088B should enable the correct selection to be made.

Aircraft cables are identified by a symbol consisting of letters and numbers, as in the symbol P2B4. Reading the designator from left to right, the code is interpreted as follows:

1. The circuit function is represented by a letter: the letter P in the example. The letters R, S, T, and X stand for radio, radar, special electronic equipment, and a-c circuits, respectively. The letters P, A, and L stand for power, armament, and lighting.

2. Each cable is assigned a cable number. In the example, P2B4, the cable number is 2. The same number is retained throughout the cable run from the power source to any piece of equipment, such as a switch. After leaving the switch the cable is then assigned a new number. The same number is retained between any two pieces of equipment joined by the cable and between one source of power and another. Cable numbers do not change at terminal blocks.

3. Each segment of cable between two terminals is given a segment letter. The segment letters run in sequence starting with a letter A. Segment letters change at terminal blocks. In the example, P2B4, the designator refer to the B segment of cable 2, which is a power carrying cable. If cable P2B4 terminates o a terminal block, the cable leaving the bloc is then called P2C4. If the cable had terminate on a switch, which is a control point, the cabl leaving the switch would then be called P3A4

4. The fourth symbol in the designator i a number representing the cable size.

5. In addition to the basic coding there ar more code letters which assist in furthe identification. The letter N is used as a la letter to indicate a cable that is attached t ground or to a negative terminal, as in P6A N. A circuit designation letter is sometime

used to identify a particular circuit, as in R L 15 F 18, where R stands for radio, L is the circuit designator and means LIAISON. The circuit designation always follows the circuit function letter.

Where two or more identical items of equipment are installed in the same aircraft, the unit number (1, 2, 3, or 4) may be prefixed to distinguish between corresponding cables of the identical items. This requirement is mandatory for equipment listed under circuit functions letters R, S, and T. An example of the unit number is the designator 2 R 16 B 14, where 2 is the unit number.

Wires are attached to terminals either with solder or by means of solderless, crimp-on terminal lugs.

A representative field procedure for soldering the wires of a cable to the terminals of an electrical connector follows:

1. Disassemble the connector to allow access to the terminals and devise a means of holding the connector so that both hands are free.

2. Strip the wire end with a wire stripper or knife. If a knife is used, avoid cutting or nicking the wire strands. Tin the bare wire end.

3. Place insulating sleeving (spaghetti) over the wires and run the wires through the connector assembly and coupling nuts. (If the connector is to be potted with THIOKOL, omit the spaghetti.)

4. See that all surfaces are clean.

5. Flow rosin-core solder into the connector terminals. Insert the wire into the terminals, holding the tip of the soldering iron against it. As the solder melts, push the wire into the cavity. Hold the wire steady while the solder cools. Care should be taken to avoid injuring the connector insulation by application of too much heat.

6. When the joint has cooled, slip the insulating sleeve over the soldered joint. When all the wires in the cable have been soldered, cooled and insulated, tie the individual wires together with string just back of the sleeve endings. This helps to prevent undue strain on the soldered joints when attaching or detaching the cable plug and the receptacle. The installation of the insulated sleeves is shown in figure 8-18.

7. Assemble the connector.

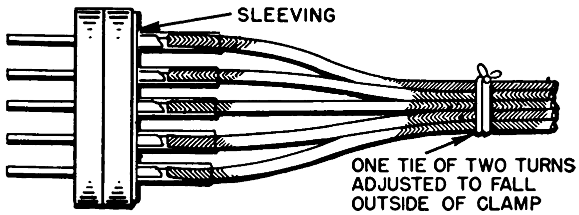


Figure 8-18.—Installation of insulating sleeving.

Terminals

Since most aircraft wires are stranded, it is necessary to use terminal lugs to hold the strands together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring diagram for the particular models. Soldered and crimped type terminals may be used interchangeably, but both must have the same amperage capacity and the same size hole in the lug.

The increased use of crimp-on terminals is due to a large degree upon the limitations of soldered terminals. The quality of soldered connections depends mostly upon the operator's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage due to heat also contribute to defective connections when they are not precisely controlled.

The crimp-on solderless terminals require relatively little operator skill. Another advantage is that the only tool necessary is the crimping tool, thus the necessity of supplying power to a soldering iron is eliminated. This allows terminals to be applied in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 8-19. (A) shows the straight type, (B) the right angle type, (C) the flag type, and (D) the splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three- and four-way splice type connectors, and others.

Since both copper and aluminum wiring is used in present aircraft, both copper and aluminum terminals are necessary. Various size terminal or stud holes will be found for

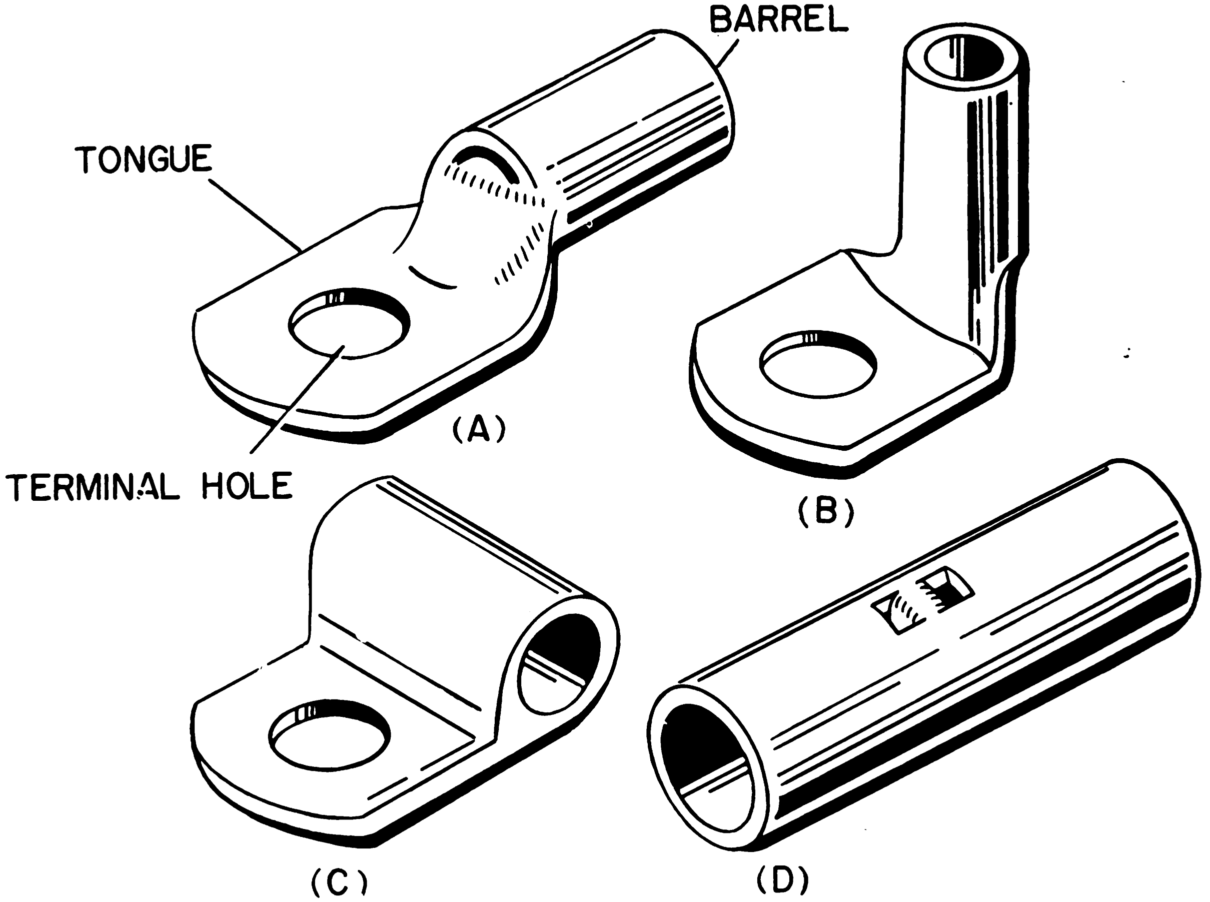


Figure 8-19.—Basic types of solderless terminals.

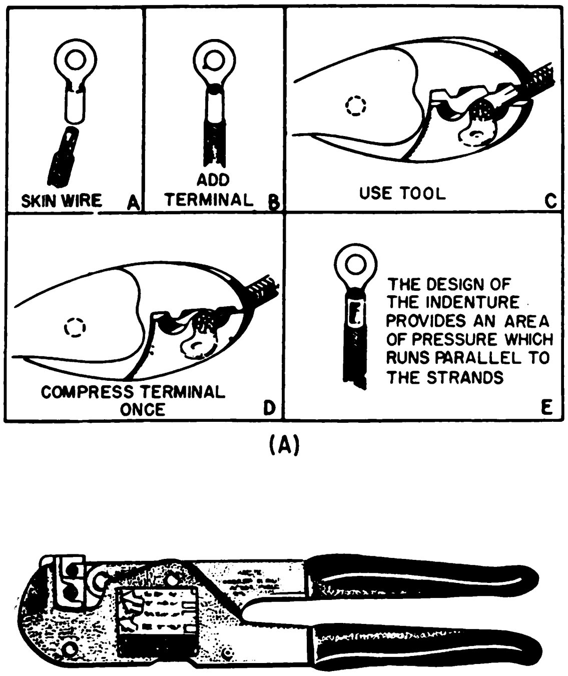
each of the different wire sizes. A further refinement of the solderless terminals is the insulated type; the barrel of the terminal (fig. 8-19) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

There are different types of crimping tools used with copper terminals. For wire sizes AWG (American Wire Gage) 10 or smaller, a small plier type of crimper is used on uninsulated terminals. (See fig. 8-20 (A).) When insulated terminals are installed, the toggle type crimper should be used. (See fig. 8-20 (B).) For the larger wire sizes, a larger and more powerful pincer type crimper is used. The small plier type crimper has several sizes of notches for the different size terminals. The large pincer type is adjusted to an index mark for the different size terminals Care should be exercised to select the corre crimping tool for the particular terminal.

The procedure for crimping a copper te minal to a copper wire is as follows:

1. Cut a 1 1/4-inch length of tubular i sulation, clear vinyl tubing, and slip it over t end of the cable. This insulation should snugly over the cable and shall be forced— over the terminal.

2. With a cable stripper or other mea (fig. 8-21), trim the insulation from the ca end for a length of 1/16 inch plus the lengt the terminal barrel. When using a cable str per, be sure to use the correct size strippi slot for the cable size used; otherwise all insulation will not be removed or, if the is too small, the outside strands of the c ductor will be nicked and consequently we ened. When using a knife for stripping ca


SKIN WIRE A
ADD TERMINAL B
USE TOOL C
COMPRESS TERMINAL ONCE D
THE DESIGN OF THE INDENTURE PROVIDES AN AREA OF PRESSURE WHICH RUNS PARALLEL TO THE STRANDS
E

(A)

(B)

Figure 8-20.—Crimping tools.

care should be used to prevent strands from being cut or nicked.

3. Slip the terminal barrel over the bared cable end and up against the insulation. Make certain that all cable strands are inside the tubular barrel of the terminal.

4. Crimp the barrel of the terminal with pecial crimping pliers of the correct size and type. Place the cable side of the terminal gainst the male staking die of the plier jaws. Center the terminal barrel in the female nest the plier jaws so that the indentation formed the staking die will be in the center of the rrel. Crimp until the pliers reach their stop limit. This is necessary for a good mechan-cal and electrical connection.

5. Slip the tubular insulation down over the ulder or barrel of the terminal so that it ends a little beyond the barrel.

Terminals that are used with aluminum e are made of aluminum and have been ed by the manufacturer. Proper crimping more difficult with these terminals because uch factors as aluminum creep and softness. softness of aluminum wire also makes it subject to being cut or nicked during stripping. Because aluminum terminals are used only with AWG size 8 and larger wire, the crimping tool is the large pincer type. You should be careful never to use an aluminum terminal with copper wire or a copper terminal with aluminum because of the battery effect. Also, never attempt to install any aluminum terminals with a copper crimping tool, and conversely, never use the aluminum crimping tool for crimping other than aluminum terminals.

The procedure for crimping an aluminum terminal to an aluminum wire is as follows:

1. Carefully remove the conductor insulation; do not cut or nick the aluminum conductors. (NOTE: Do not wire-brush or scrape the aluminum conductor; the compound in the terminal barrel will clean it satisfactorily.)

2. Remove the protective foil wrapping from the terminal and check the amount of compound in the terminal barrel. It should be 1/4 to 1/2 full.

3. Insert the stripped conductor the full length of the terminal barrel. While doing this, the thumb must be held over the inspection hole so that the compound is forced in and around the strands.

4. Center the terminal in the crimping tool.

5. Close the handle all the way, until the movable handle meets the stop.

6. Wipe off the excess compound. Inspect the joint with a probe through the inspection hole. The end of the conductor should come to the edge of the inspection hole.

Improper crimping procedures will eventually cause terminal failure. Be particularly careful of undercrimping, overcrimping, the use of wrong crimping tools, improper cleaning methods, and cutting or nicking the conductors. A loose contact will allow an oxide film to form between the wire and terminal; this will result in increased resistance and the resistance will cause heat. The heat will accelerate the deterioration and eventually results in a failure. A lockwasher should never be used next to an aluminum terminal since it will gouge out the tinned area and thus increase deterioration. A flat washer should be used, thus preventing the revolving nut from scratching the tinned area or causing creep of the aluminum terminal.

If the correct tools are used and the proper procedures followed, the connections will be more effective electrically, as well as mechanically, than soldered connections. A visual inspection is very important, it will reveal

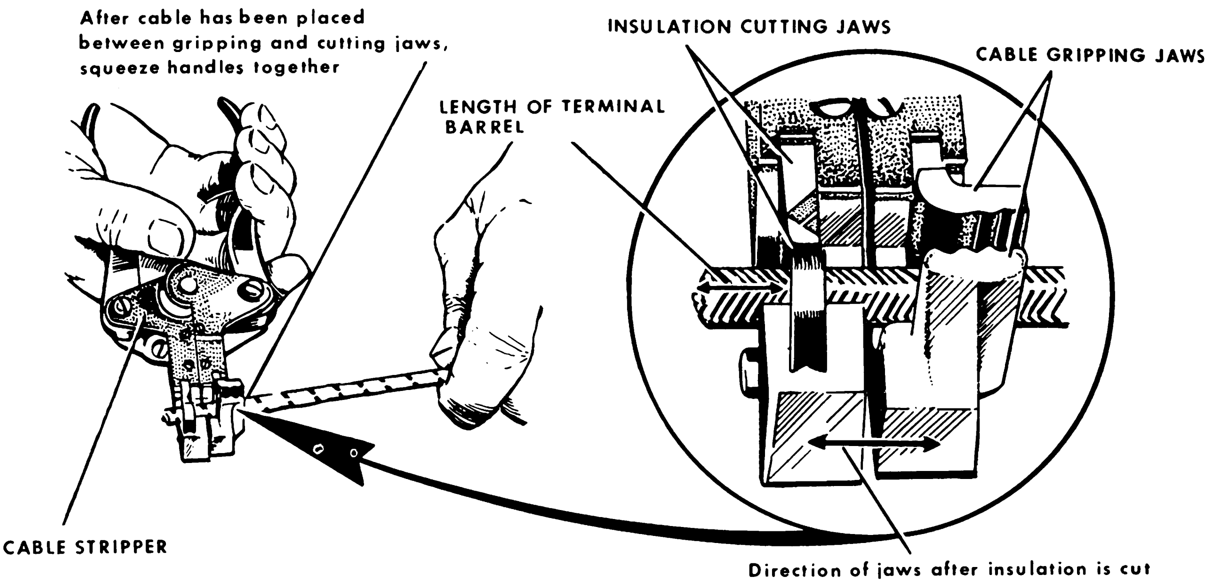

After cable has been placed between gripping and cutting jaws, squeeze handles together
INSULATION CUTTING JAWS
CABLE GRIPPING JAWS
LENGTH OF TERMINAL BARREL
CABLE STRIPPER
Direction of jaws after insulation is cut

Figure 8-21.—Cable stripper.

oxidation, deterioration, overheating, and broken conductors. In some cases it may be necessary to check these connections with an ohmmeter, the proper resistance, for all practical purposes, should be zero. Any defective terminal should be removed and a new terminal crimped on.

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

Consult section XII of *Engineering Handbook Series for Aircraft Repair, Aircraft Structural Hardware* (AN 01-1A-8) and/or *Handbook Installation Practices for Aircraft Electrical and Electronic Wiring,* NavAer 01-1A-505, for detailed information dealing with attaching cable terminals, forming terminals for emergency use, and repairing damaged or broken cables.

Terminal blocks are made from an insulating material which supports and insulates a series of terminals from each other as well as from ground. They provide a means of installing terminals within junction boxes and distribution panels.

Two methods of attaching cable terminals to terminal blocks are illustrated in figure 8-22. In (A) of the figure a standard nonlocking nut is used. In this method of installation, the use of a lockwasher (AN 935) is necessary. The preferred method is shown in (B) of the figure. An anchor nut, or self-locking nut, is used and the lockwasher is omitted. The use of anchor nuts is especially desirable in areas of high vibration. In both installations, it is required that a flat washer (AN 960) be employed, as shown in the drawing.

Junction boxes are installed to accommodate electrical terminals or other equipment, such as relays and transformers. Individual junction boxes are named according to their function, location, or equipment with which they are associated. Examples are lower main junction box and forward right inboard junction box Junction boxes are provided with a drain hole (except boxes labeled "vaportight") located a the lowest point so that water, oil, condensate or other liquids will not be trapped.

Support Clamps

Clamps are used to provide support for ope wiring, and to serve instead of lacing on ope wiring. They are usually supplied with a rubber cushion. When used with shielded conduit the clamps are of the bonded type (fig. 8-23 **(A)**) that is, provision is made for electrical **con**tact between the clamp and conduit. **Unbonde** clips are used for the support of open **wiring**

Long runs of cable between panels are supported either by a strap type clamp, shown in (B) of figure 8-23, or by an AN 742 clamp, shown in (C) of the same figure. The preferred method of supporting cables for all types of runs is with AN 742 clamps. When the strap type clamp is used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft; these clamps should be used only as an emergency measure.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 8-24. The cable should be routed well in the clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.

Cable Lacing and Tying

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. The purpose of lacing or tying is to keep all cables neatly secured in groups and to avoid possible damage from chafing against equipment or interference with equipment operation.

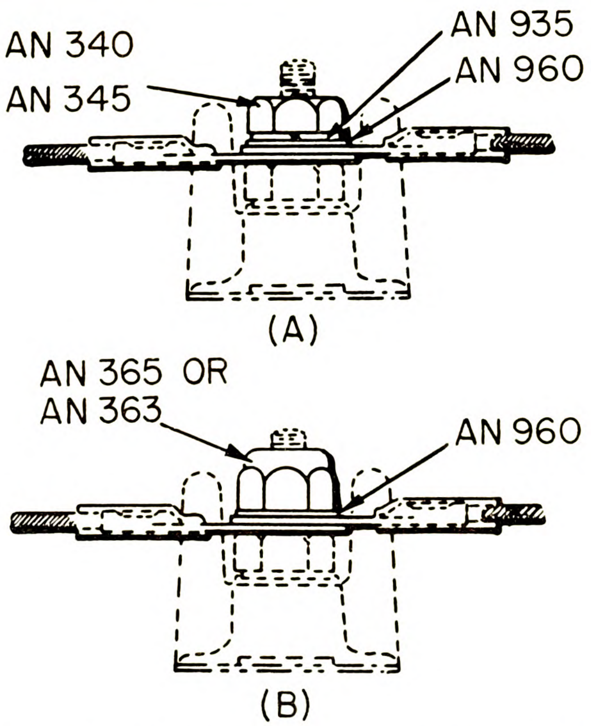
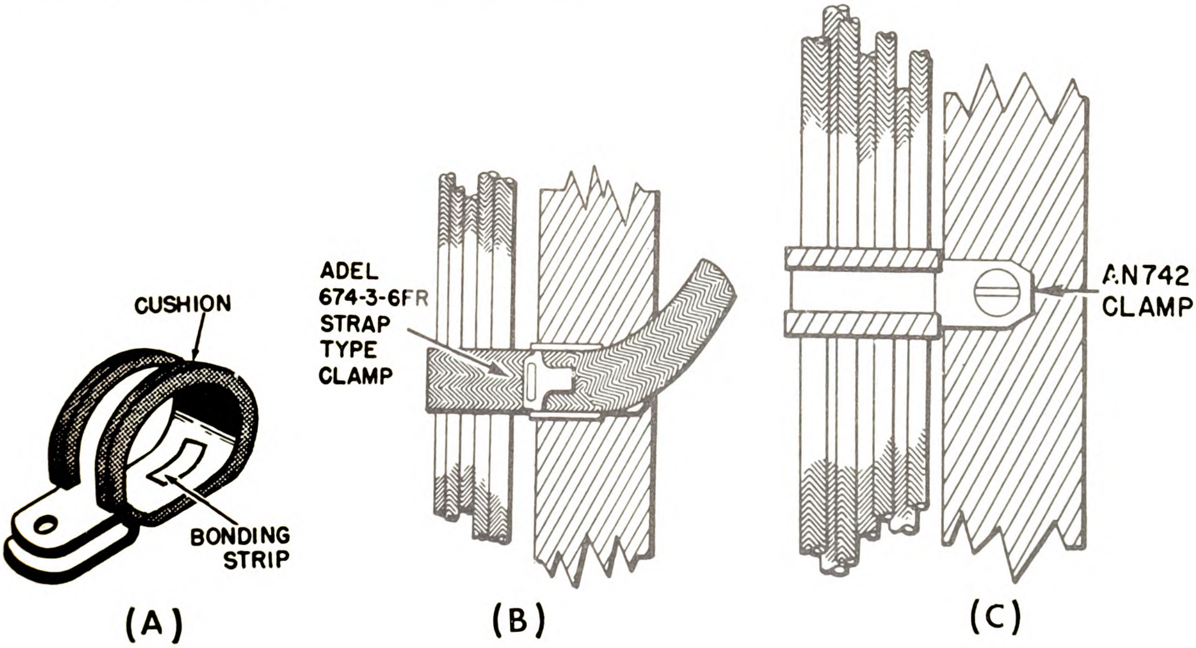


Figure 8-22.—Installation of cable terminals on terminal block.



(A) (B) (C)

Figure 8-23.—Cable clamps.

Tying is the securing together of a group or bundle of wires by means of individual pieces of cord tied around the group or bundle at regular intervals. Lacing is the securing together of a group or bundle of wires inside enclosures by means of a continuous piece of

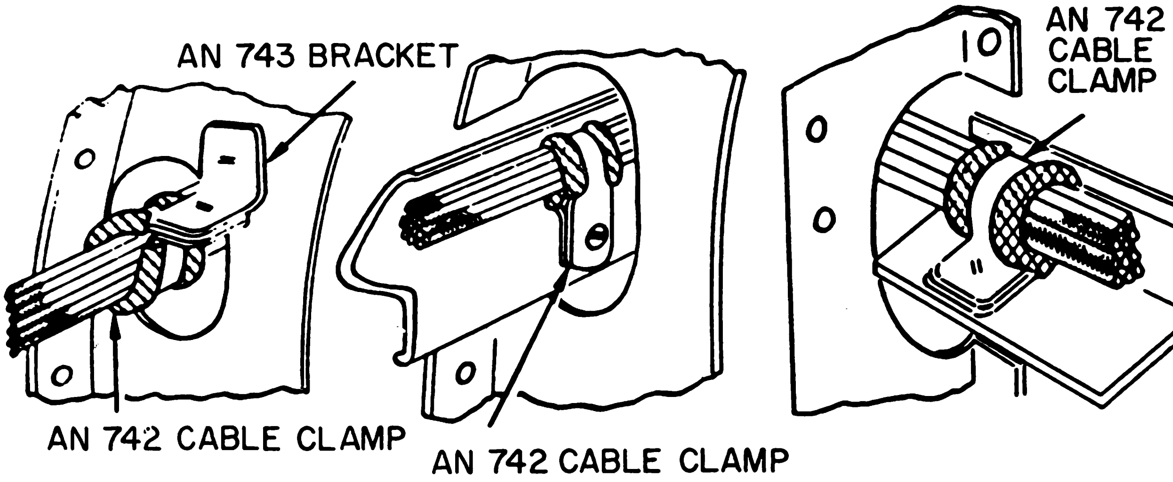


Figure 8-24.–Routing cables through lightening holes.

cord forming loops at regular intervals around the group or bundle.

Cotton, nylon, or fiberglass cord is used for tying or lacing. The cotton cord must be waxed to make it moisture and fungus resisting. Nylon and fiberglass cords are in themselves moisture and fungus resisting and are not usually waxed. Pressure sensitive vinyl electrical tape is used only where the use of tape instead of cord is specifically permitted.

When lacing or tying, observe the following precautions:

1. Lace or tie bundles tight enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductor.
2. Do not place ties on that part of a wire group or bundle that is located inside a conduit.

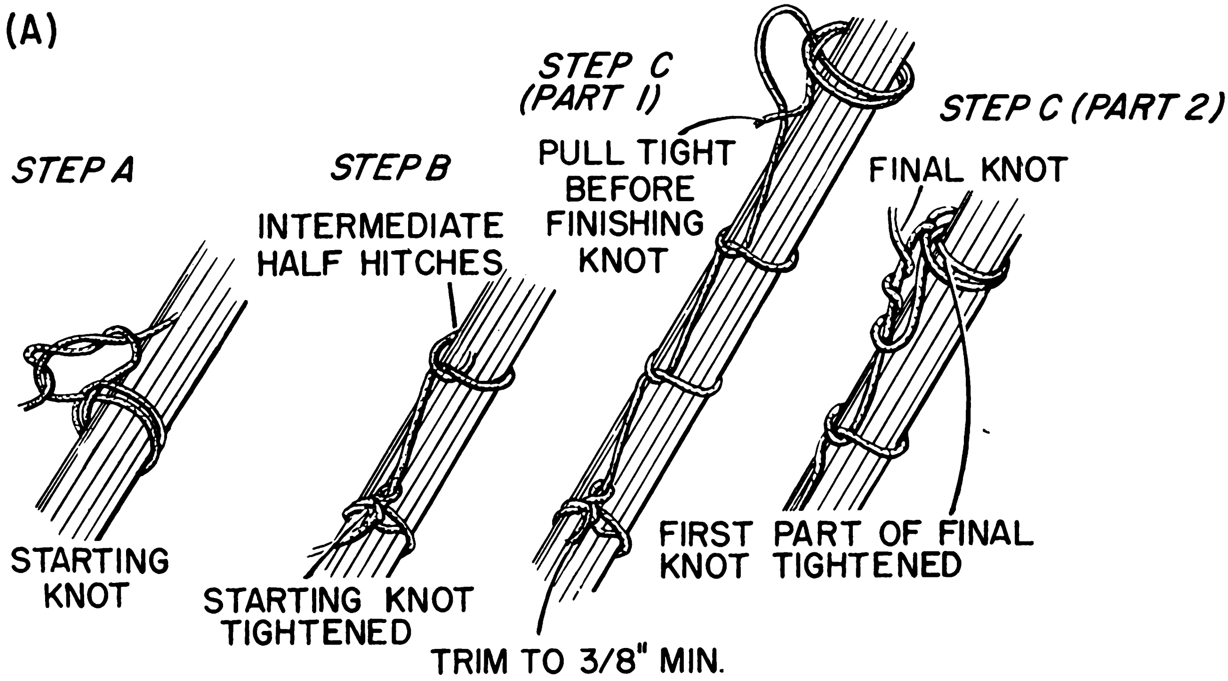
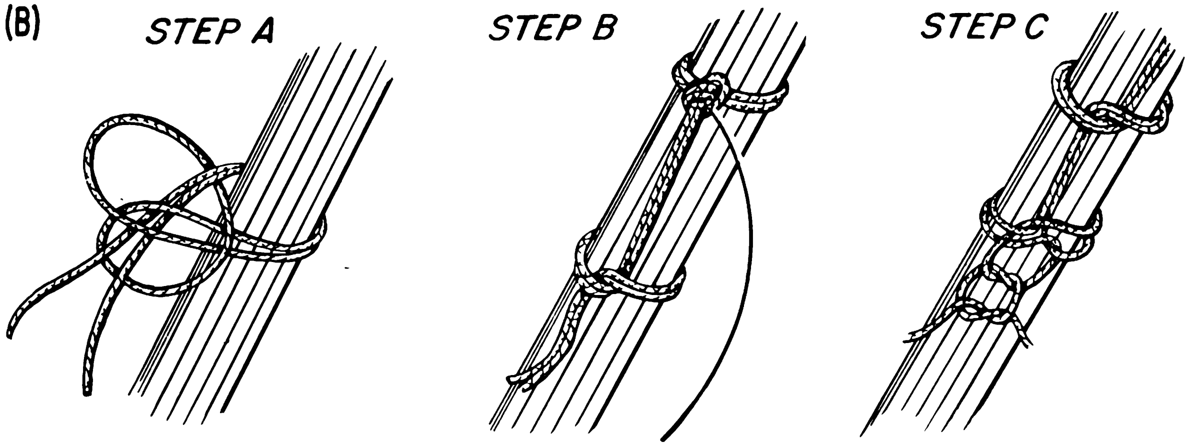


Figure 8-25.–Lacing groups or bundles.



STARTING KNOT-
BOWLINE ON A BIGHT

STARTING KNOT
TIGHTENED

INTERMEDIATE
HALF HITCHES

Figure 8-25.—Lacing groups or bundles—Continued.

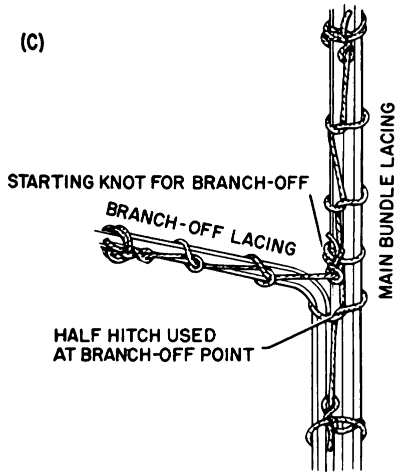


Figure 8-25.—Lacing groups or bundles—Continued.

3. Lace wire groups or bundles only when they are inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than one inch in diameter. Use single or double cord for groups or bundles one inch or less in diameter. (NOTE: A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.)

Single cord lacing (fig. 8-25 (A)) is performed as follows:

1. Start the lacing at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop.
2. At regular intervals along the wire group or bundle, and at each point where a wire or wire group branches off, continue the lacing with half hitches. Space the half hitches so that the group or bundle is neat and securely held.
3. End the lacing with a knot consisting of a clove hitch with an extra loop.
4. Trim the free ends of the lacing cord to 3/8 inch minimum.

Double cord lacing (fig. 8-25 (B)) is performed as follows:

1. Start the lacing at the thick end of the wire group or bundle with a bowline on a bight.
2. At regular intervals along the wire group or bundle, and at each point where a wire group branches off, continue the lacing with half hitches, holding both cords together.
3. End the lacing with a knot consisting of a half hitch, using one cord clockwise and the other counterclockwise, and then tying the cord ends with a square knot.
4. Trim the free ends of the lacing cord to 3/8 inch minimum. The lacing of a wire group that branches off the main wire bundle is shown in figure 8-25 (C).

Tie all wire groups or bundles where supports are more than 12 inches apart. Space the ties 12 inches or less apart. (See fig. 8-26 (A).) The steps in making ties are as follows:

1. Wrap cord around wire group or bundle.
2. Make a clove hitch, followed by a square knot with an extra loop.
3. Trim free ends of cord to 3/8 inch minimum. Temporary ties are used to aid in making up and installing wire groups or bundles. Use colored cord to make temporary ties, and

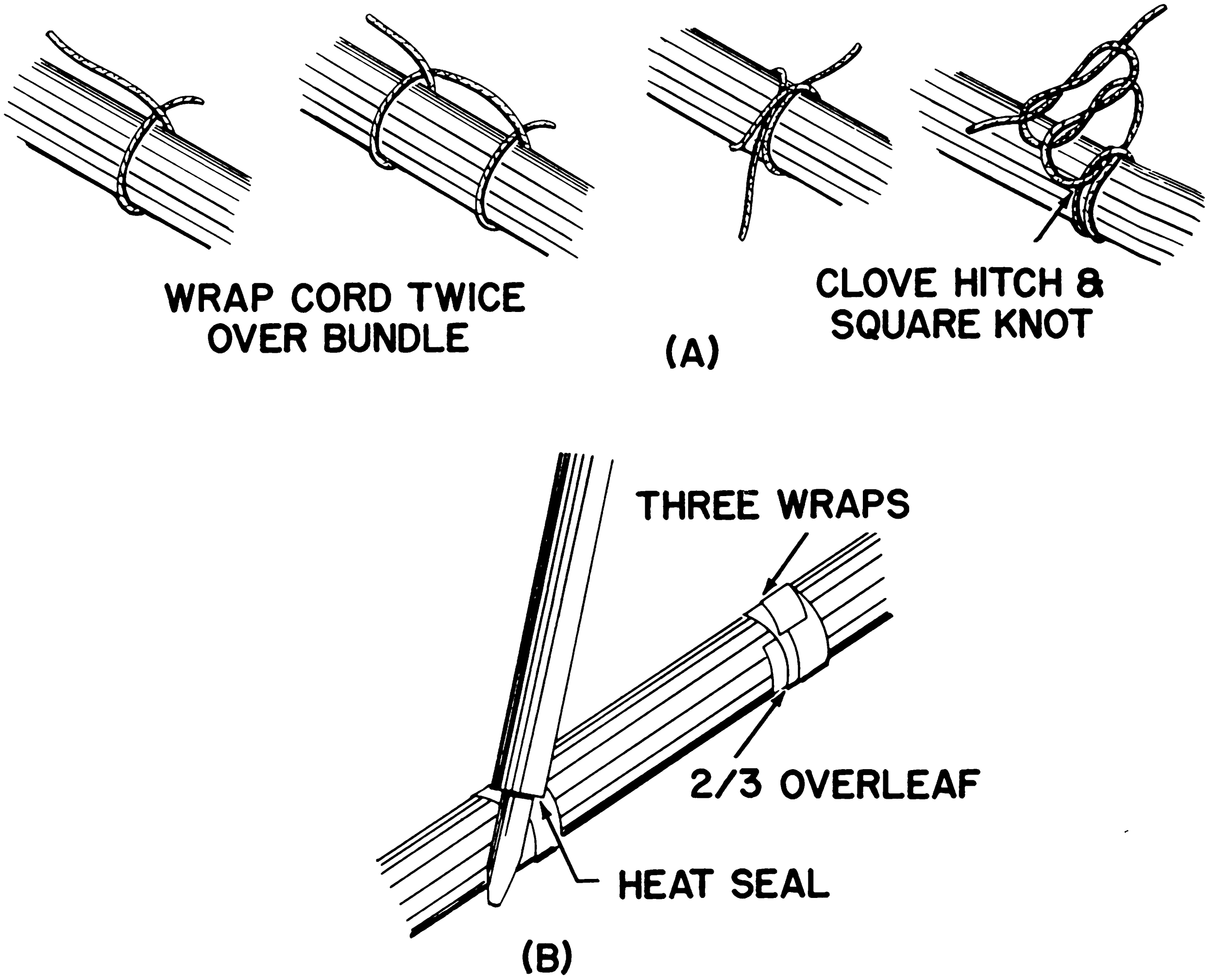


Figure 8-26.—Tying groups or bundles.

remove such ties when the installation is complete. Cut temporary ties with scissors or diagonal pliers only. Do not use a knife or other sharp edged instrument which may damage the insulation.

In some instances groups or bundles may be secured with tape. (See fig. 8-26 (B).) The following method should be employed:

1. Wrap tape around wire group or bundle three times, with a two-thirds overlap for each turn.

2. Heat-seal the loose tape end with the side of a soldering iron heating element.

Do not use tape for securing wire groups or bundles which may require frequent maintenance.

An excellent source of additional information in connection with power distribution is NavAer 01-1A-505, *Handbook Installation Practices for Aircraft Electric and Electronic Wiring*. This handbook presents the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring. It includes information under the following headings: Wire and cable preparation; general-purpose connectors; RF connectors and cabling; solderless terminations and splicings; thermocouple wire soldering and installation; bonding and grounding; bus bar preparation; conduit fabrication; installation of bus bars, conduit, junction boxes, protective devices, and terminal strips; electrical wiring installation; lacing and tying; safety wiring; and emergency repairs.

Bonding and Bonding Devices

A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the component metallic parts of the aircraft. An isolated conducting part or object is one that is physically separated by intervening insulation from the aircraft structure and from other conductors which are bonded to the structure.

A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft not in sufficient electrical contact. Examples of bonding connectors are bonding jumpers and bonding clamps.

Purpose

Clouds may become highly charged as is evidenced by lightning. An aircraft can also become highly charged while in flight. If the aircraft is improperly bonded, all metal parts will not have the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance, due to such causes as intermittent contact from vibration or the movement of the control surface, will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is great enough, charges can accumulate until the potential difference becomes high enough to cause a spark. In addition to creating radio interference, this also constitutes a fire hazard. In the case of lightning striking the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks which would damage the airplane and possibly its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance must be maintained between the aircraft structure and antenna. This neans the surface area of the ground must be onstant. Control surfaces, for example, may t times become partially insulated from the emaining structure due to a film of lubricant on ie hinges. This would affect radio operation if ie condition were not taken care of by bonding.

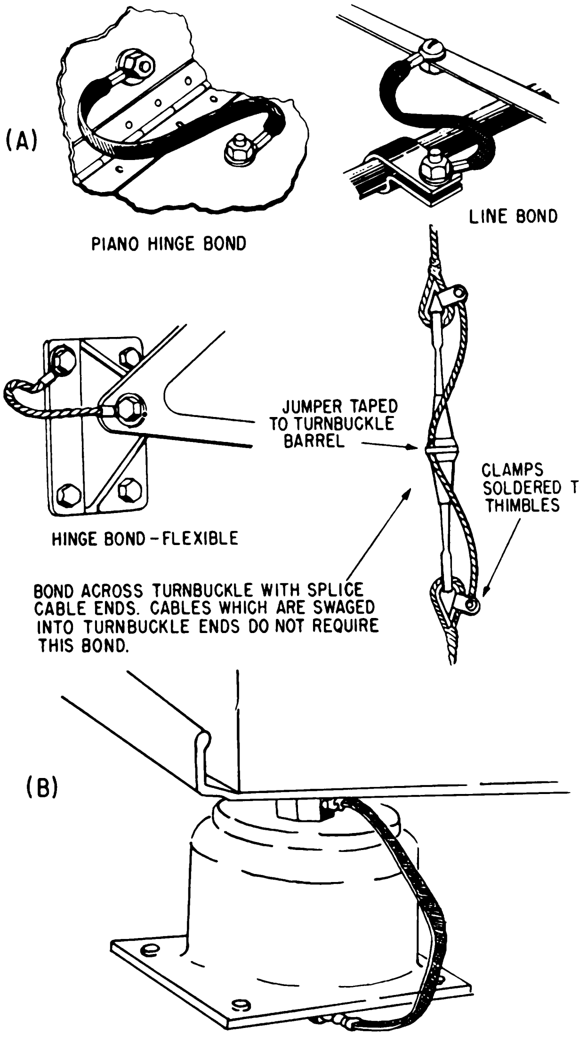

(A)
PIANO HINGE BOND
LINE BOND
HINGE BOND - FLEXIBLE
JUMPER TAPED TO TURNBUCKLE BARREL
CLAMPS SOLDERED TO THIMBLES
BOND ACROSS TURNBUCKLE WITH SPLICE CABLE ENDS. CABLES WHICH ARE SWAGED INTO TURNBUCKLE ENDS DO NOT REQUIRE THIS BOND.
(B)

Figure 8-27.—Bonding methods.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance return path also aids the effectiveness of the shielding, and provides a means of bringing the entire aircraft to the earth potential when it is grounded.

The reasons for bonding may be summed up as follows:

1. To minimize radio and radar interferences by equalizing static charges that accumulate.
2. To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark.
3. To minimize lightning damage to the aircraft and its occupants.
4. To provide the proper "ground" for proper functioning of the aircraft radio.

5. To provide a low-resistance return path for single-wire electrical systems.

6. To aid in the effectiveness of the shielding.

7. To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth.

Bonding connections should be installed so that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connections nor loosen them to such an extent that the resistance will vary during the movement. The bonding that will be of most concern to the AT will be the bonding jumpers that are placed across shock mounts, used to support electronic equipment.

Since a primary objective for bonding is to provide an electrical path of low d-c resistance and low RF impedance, it is important that the jumper be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. Parts should be bonded directly to the basic aircraft structure rather than through other bonded parts insofar as practical. Bonding jumpers should be installed in a manner so as not to interfere in any way with the operation of movable components of the aircraft.

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) which causes a pitting in one of the metals. The intensity of this electric action varies with the kinds of metals. Bonding frequently necessitates the direct contact of dissimilar metals. In such cases the metals used are of the kind that will produce a minimum of corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than in the bonded or bonding members.

Self-tapping screws should not be used for bonding purposes nor should jumpers be compression-fastened through plywood or other nonmetallic material. When performing a bonding operation, the contact surfaces should be cleaned of insulating finishes or surface films before assembly, and then the completed assembly refinished with a suitable protective finish.

Consult *Handbook Installation Practices for Aircraft Electric and Electronic Wiring,* NavAer 01-1A-505, for detailed information dealing with bonding.

Safety Wiring

Parts, such as drilled-head bolts, fillister-head screws, clips, thumbscrews, plugs, and similar items, are safetied with wire. Corrosion resisting steel lock wire is usually used for this purpose. Annealed corrosion-resisting wire is also used for specific applications, such as where nonmagnetic qualities and heat resisting properties are desired. For securing emergency devices, where it is necessary to be able to break safety wire quickly, use aluminum or copper lock wire. An example of the method of wiring is shown in figure 8-28.

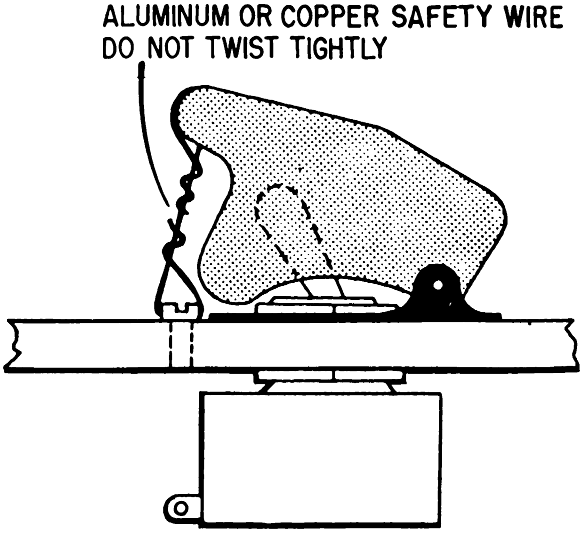


Figure 8-28.—Safety wiring switch guard.

The double-twist method is the most common method of safety wiring, and should essentially be as shown in figure 8-29. The twisting may be accomplished by hand with the exception of the final few twists which shoul be done with pliers in order to apply tensio and secure the ends of the wire properly. Th safety wire should always be installed an twisted so that the loop around the head stay down and does not tend to come up over th volt head, causing a slack loop. Extreme car must be used when twisting the wires togethe to insure that they are tight but not overstresse to the point where breakage will occur unde slight load or vibration.

The single-twist method of safety wiring ma be used on small screws in a closely space area providing the screws form a closed geometrical pattern. Figure 8-28 illustrates

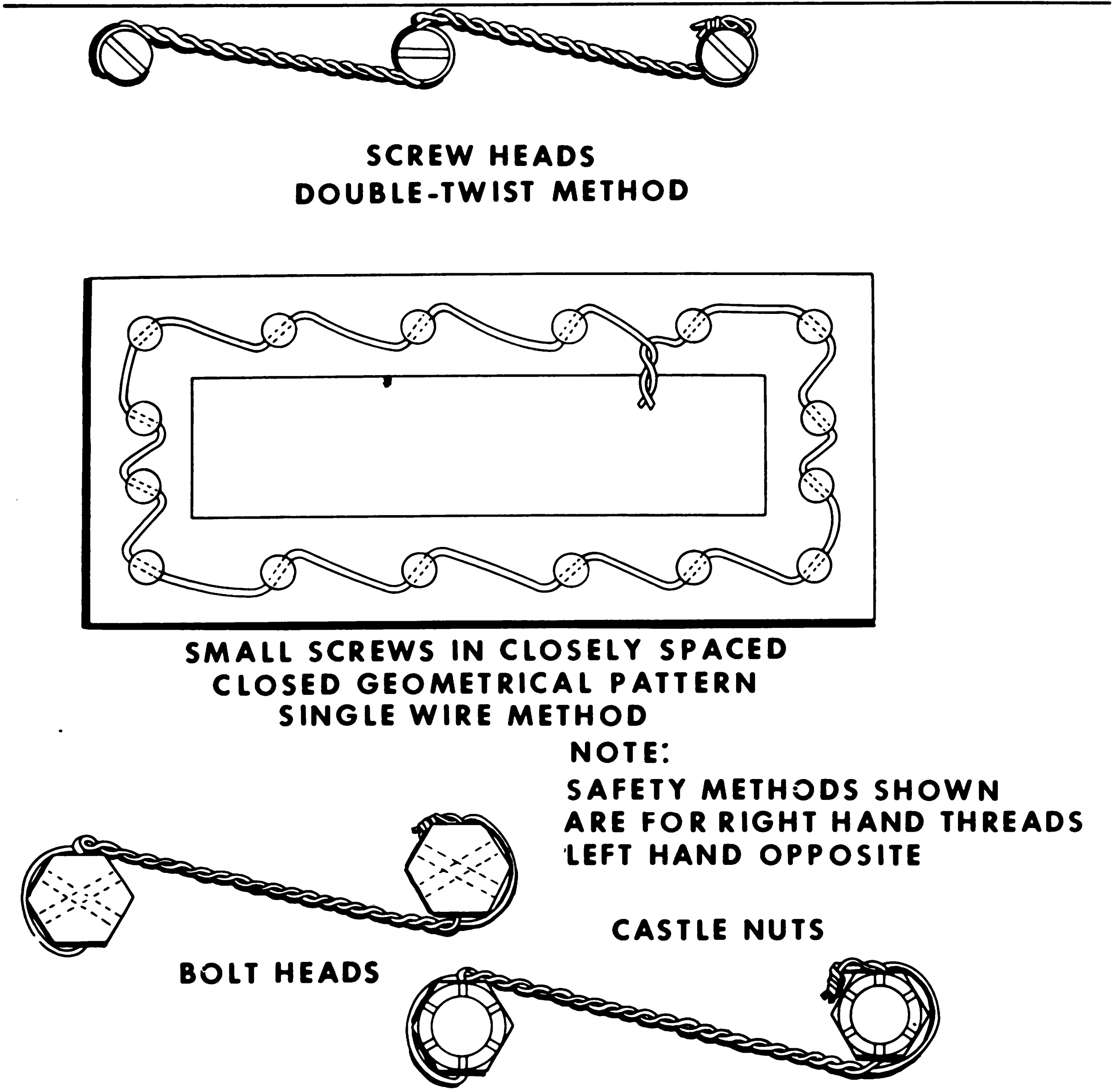


Figure 8-29.—Safety wiring.

typical application where the single-wire method may be used.

Finished ends of safety wire should be bent back or under to PREVENT INJURY to personnel.

Under conditions of severe vibration, the coupling nut of an AN connector may vibrate loose; and with sufficient vibration, the connector will come apart. When this occurs, the circuit carried by the cable will open. The proper protective measure to prevent this occurrence is by safety wiring as shown in figure 8-30. The safety wire should be as short as practicable and must be installed in such a manner that the pull on the wire is in the direction which tightens the nut on the plug.

In aviation electronic equipment there will be other parts and devices which require safety wiring to prevent loosening, parting, or changing of position. The procedure given for the safety wiring of bolts needs only slight modification to fit the particular situation. Whenever a safety wire is broken for maintenance or other cause, it must be replaced using the proper procedure. Any time a required safety wire is NOT replaced, an inflight failure may result.

When drilled-head bolts, screws, or other parts are grouped together, they are more conveniently safety wired to each other or in series rather than individually. The number of bolts, screws, nuts, and so forth, that may be safety wired together is dependent upon the application. For instance, when safety wiring widely spaced bolts by the double-twist method, a group of three should be the maximum number in a series. When safety wiring closely spaced bolts, the number that can be safety wired by a 24-inch length of wire should be the maximum number in a series. The wire is arranged in such manner that if either a bolt, screw, or a threaded item begins to loosen, it will have force applied in the tightening direction. Parts being safety wired should be torqued to recommended values and holes alined before attempting to proceed with the safetying operation. Never overtorque or loosen a torqued nut to aline safety wire holes.

General Maintenance

COMMUTATOR, BRUSH, AND SLIPRING

The connection of the armature conductors to the individual commutator segments is made at the part of the segment referred to as the "riser." This connection is secured by use of hard solder or silver solder. Insulation of all segments from each other and from the armature shaft and core is accomplished by thin sections of mica between each segment and between the segments and the clamps which hold the segments to the shaft. The mica between the segments is cut to the same shape as the segments. That part of the mica directly under the brush is cut below the surface of the commutator bars.

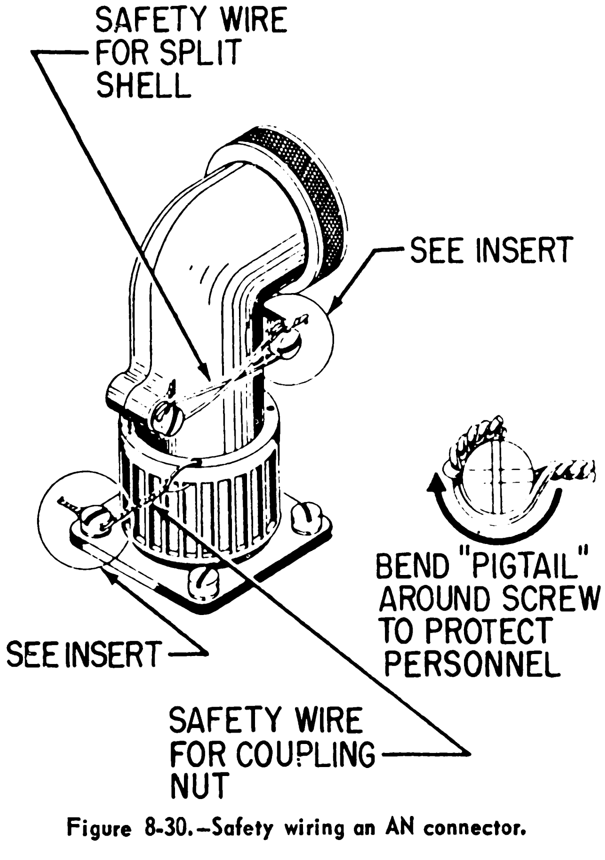

SAFETY WIRE FOR SPLIT SHELL
SEE INSERT
BEND "PIGTAIL" AROUND SCREW TO PROTECT PERSONNEL
SEE INSERT
SAFETY WIRE FOR COUPLING NUT

Figure 8-30.—Safety wiring an AN connector.

When shop checking, check to see that the commutator has a smooth, worn surface around the entire circumference throughout the area spanned by the brushes. It should have an even brown or chocolate color. Any dirt, oil, or grease on the commutator must be removed. Check for brush sparking as evidenced by rough and pitted commutator bars. Look for loose connections to the commutator risers. This may be indicated by specks of solder on the surrounding field coils and connections.

Should the commutator be dirty, it must be cleaned. Oil and dirt tend to glaze the surface with a high-resistance coating. Remove the brushes; blow loose dirt out with air, being careful not to blow it into the housing. Wipe oil and grease out with a lintless cloth moistened with the appropriate cleaning solution. A high-resistance coating may be removed with No. 0000 or finer sandpaper (not emery cloth) folded over a flat thin stick to hold the sandpaper in perfect contact with the commutator. (NOTE: There are various methods of cleaning commutators. The sandpaper method is recommended in most cases.) Rotate the shaft slowly, moving the stick sideways to reach the whole width of the commutator bars.

Do not hold the sandpaper in one position, as this will groove the commutator. Use light, even pressure. Blow out the dust with dry clean compressed air and wipe off with a lintless rag dampened with the appropriate cleaning solvent.

As the surface of the commutator gradually wears, the mica will eventually become flush with the brush surface of the segments. If this condition is not corrected by undercutting the mica, rapid brush wear is apt to result. Extreme care must be taken when undercutting to prevent the cutting tool from leaving the slot and scoring the brush surface of the commutator; also, great care must be exercised to avoid sharp edges on the commutator bars.

The following checks should be made when checking the generator brushes and brush-rigging. Look for cracks in the brush-holder yoke and check for tightness. Check for loose screws and defective safety wires. Check for loose brush holders and for dirt, grease, and oil. Check for security of jumper leads between holders of like polarity. Check to see that no brush holder is bent out of alinement. Check for broken brush springs. Check freedom of brush in brush holder. The brush should not bind or drag in the holder, but neither should there be enough clearance that a sloppy fit is obtained. Check all brushes for security of pigtail to brush and to terminal, and to see that the wire is not worn or frayed.

Check the brushes to see that they are not cracked or chipped. Check for pits due to sparking. Check for oil-soaked brushes. If the brush is oil soaked, it must be replaced. The oil acts as an insulator and terminal voltage will be lowered.

When replacing the original brushes, make certain that they are replaced in their original holders; otherwise, it may be necessary to refit the brushes. When brushes are placed in their holders, the brush springs should be carefully lowered until they make contact with the brush. Never release the brush spring unless it is in contact with the brush since this will allow the spring to strike the brush sharply, causing possible damage to the brush. Check for brush wear by measuring the length of the brush. It must be within the limits specified by the manufacturer.

When it becomes necessary to install new brushes, the following procedure is recommended. Pull brush springs back only as far as necessary to allow removal of old brushes; this may be easily done by using a hook made of stiff wire. Attach brush pigtails of new brushes to proper connections and secure electrically. Insert brushes in brush holders. After the new brushes have been installed, steps must be taken to remove the old commutator film, fit the new brushes, and establish a new film.

The sliprings of a-c machines must be inspected periodically for smoothness of surface, diameter of the rings, and alinement of the rings on the shaft.

In routine maintenance of sliprings, cleaning and polishing is accomplished by using No. 0000 sandpaper or some finer grade. Emery cloth or coarse sandpaper should never be used. Emery cloth is a conductor and can cause shorts, while coarse sandpaper will groove the commutator deeply. All sand particles should be blown from the rotor with dry compressed air after cleaning.

BEARING CARE OF ROTATING EQUIPMENT

Antifriction bearings are either ball or roller bearings. These, especially ball bearings, are widely used in aircraft rotating electrical machinery such as dynamotors, inverters, generators, and motor generators. In modern electrical machines, extensive use of sealed bearing assemblies is made. This makes maintenance and lubrication very easy since sealed bearings are prelubricated and require almost no attention during normal operation of the machine in which they are installed.

As a guide to proper maintenance of ball bearings in dynamotors and other aircraft equipment, the detailed recommendations of the manufacturer as given in the *Handbook of Service Instructions* should always be followed. Excessive lubrication leads to bearing trouble, and an undue amount of grease in the slipring or commutator compartment of the machine may result. Brush and slipring wear increases appreciably if a large amount of lubricant is present. Excessive lubricant should be removed with a cleaning solvent, and the bearings properly lubricated.

QUIZ

1. An aircraft preflight inspection will
    a. be accomplished at any time prior to a scheduled flight
    b. be the responsibility of the pilot only
    c. often reveal defects that could cause accidents or aborted missions
    d. normally be confined to the mechanical aspect of the aircraft if the assigned mission does not require electronic equipment
2. In troubleshooting a communications receiver, what would be the most logical sequence of checks for locating the trouble?
    a. Voltage, resistance, current
    b. Visual, voltage, resistance
    c. Visual, resistance, voltage
    d. Voltage, current, resistance
3. As a technician on a troubleshooting assignment, your job may be considered completed after
    a. the "squawk sheet" is signed
    b. diagnosing the trouble and supervising nonrated personnel in replacing the defective part
    c. the repaired equipment is properly reinstalled in the aircraft and given an operational check
    d. the equipment is repaired and bench checked in accordance with the prescribed procedures contained in the HSI
4. Detailed instructions for performing sealing operations of AN electrical connectors is found in the
    a. data sheet which comes with the sealing compound
    b. Handbook of Service Instructions
    c. current Electronic Material Change covering the subject
    d. data sheet which comes with the connector
5. The purpose of safety wire is to
    a. secure emergency devices only
    b. prevent loosening, parting, or changing of position of devices susceptible to vibration
    c. provide a d-c ground for electronic equipment isolated from ground by rubber shock mounts
    d. eliminate the need for locknuts or lockwashers
6. A defective unit of electronic equipment discovered during a preflight check
    a. will never be just cause for "downing" an aircraft
    b. will always be just cause for "downing" an aircraft
    c. must always be noted on the "yellow sheet"
    d. must always be referred directly to the pilot scheduled to fly the aircraft
7. As a general rule, which of the following provides the quickest method of isolating a faulty stage in electronic equipment?
    a. Voltage measurement
    b. Current measurement
    c. Resistance measurement
    d. Signal tracing
8. Before attempting a parts replacement in a printed circuit, a technician should
    a. thoroughly familiarize himself with the prescribed techniques related to the job.
    b. make every effort to obtain a complete new subassembly or unit
    c. obtain permission from higher authority
    d. obtain the many special tools necessary for the job
9. The purpose of soldering a short length of wire to each spare pin of a potted connector is
    a. to provide a uniform base for the sealing compound to adhere
    b. to provide for additional circuit requirements that may arise
    c. to provide a means of splicing around a broken wire within the connector
    d. both b and c are correct
10. Which of the following is NOT a true statement?
    a. A commutator having a brown or chocolate color requires no action since it is a normal indication
    b. Oil or dirt on a commutator tends to glaze the surface with a high-resistance coating.
    c. Of the various methods of cleaning commutators, grade 0000 sandpaper is recommended in most cases
    d. It is never necessary to remove carbon dust from a dynamotor
11. It is important that permission be obtained before removing a defective unit of electronic equipment from an "up" status aircraft because
    a. it aids in maintaining accurate records
    b. it could possibly entail unnecessary work if there is no anticipated need for the equipment
    c. flight characteristics of the aircraft may be affected by the change in weight and balance
    d. it insures that the pilot will be informed of the discrepancy

12. A signal generator delivers 350 microvolts to the grid of an IF amplifier, causing an output meter to indicate a reference value. When applied to the following grid, the signal generator voltage must be raised to 2,800 microvolts to furnish the same reference value. What is the gain of the IF stage?
    a. 7
    b. 8
    c. 9
    d. 10

13. When soldering semiconductors such as transistors or crystal diodes, it is advisable to use a heat shunt. What is the purpose of the heat shunt?
    a. It will provide a rapid transfer of heat from the soldering iron to the work, thereby minimizing the time heat must be applied
    b. It protects, to some degree, the semiconductor from excessive heat
    c. It allows the technician a greater choice of soldering irons
    d. It allows the use of a solder having a higher melting point, thereby resulting in a more secure low-resistance electrical connection

14. An aircraft cable has the following symbol: S15A22N. This does NOT indicate the
    a. circuit identification
    b. cable length
    c. cable number
    d. cable size

15. Which of the following type inspections would be performed prior to the first flight cf the day's operations?
    a. Calendar
    b. Periodic
    c. Daily
    d. Intermediate

16. Periodic inspections differ from daily or preflight inspections in that
    a. more experienced personnel are assigned to periodic inspections
    b. periodic inspections are more searching and thorough
    c. periodic inspections are performed on specific calendar dates
    d. all of the above are correct

17. When making stage gain measurements in receivers, how may the technician best determine the correct value of input voltage required from the signal generator?
    a. By consulting the Handbook of Service Instructions
    b. By selecting a signal high enough to allow the avc system to function
    c. By increasing the output from the signal generator until the recommended gain is obtained
    d. By computing the amount required to produce 1.73-volt drop across a 300-ohm load

18. Information relating to troubleshooting and repair of an aircraft's electronic wiring system would be found in
    a. the Handbook of Service Instructions
    b. the Handbook of Maintenance Instructions
    c. the Handbook of Installation Practices for Aircraft Electric and Electronic Wiring
    d. all of the above

19. Crimp-on solderless terminals are widely used in aircraft systems. An advantage of using such terminals is
    a. the resulting low-resistance connection
    b. cleaner, more uniform connections
    c. the relatively little operator skill required
    d. all of the above

20. Which of the following is NOT a true statement?
    a. The need for bearing lubrication has been entirely eliminated by the use of sealed bearing assemblies
    b. Excessive use of bearing lubricant will cause increased wear of slip-rings and brushes
    c. Excessive lubricant should be removed with a cleaning solvent
    d. The manufacturer's recommendations for bearing lubrication can be found in the Handbook of Service Instructions

21. An acceptance or transfer inspection is performed on an aircraft when a squadron transfers it or receives it. The primary purpose is to
    a. insure that all discrepancies have been corrected
    b. determine if field changes have been incorporated
    c. determine if the aircraft logbooks are up to date with all appropriate entries made
    d. all of the above are correct

22. Before replacing a defective part in any electronic equipment, it will always be necessary to
    a. have the shop chief verify the need for replacement
    b. ascertain if such an operation may be performed by your unit or squadron
    c. consult the Illustrated Parts Breakdown for the equipment in question
    d. investigate the possibility of modifying the circuit to prevent similar failures in the future

23. A 500-ohm resistor must be replaced with a unit which has a tolerance of 20 percent. If 48 volts are normally dropped across the original resistor, what would be the most satisfactory replacement wattage?
    a. 5 watts
    b. 7 watts
    c. 10 watts
    d. 15 watts

24. Which of the following statements is true?
    a. AN 742 clamps are normally preferred for all types of cable runs
    b. Only shielded cable is routed through a lightening hole
    c. The most common means of preventing chafing is to employ shielded conduit
    d. Terminal blocks are made from an insulating material and eliminate the need for junction boxes

25. A soldering "gun" should not be used when repairing transistorized equipment because
    a. its electric field may cause excessive currents and damage the transistor
    b. it gets too hot
    c. its heat cannot be conveniently controlled
    d. it does not get hot enough

26. As a technician, your biggest asset to rapid and efficient troubleshooting will be a/an
    a. complete set of operating spares
    b. full allowance of accurately calibrated test equipment
    c. systematic plan based upon a "common sense" approach
    d. appropriate Handbook of Maintenance Instructions

27. Information concerning the general nomenclature and physical characteristics of a part would most likely be found in which publication?
    a. Illustrated Parts Breakdown
    b. Handbook of Service Instructions
    c. Handbook of Maintenance Instructions
    d. Standard Aeronautical Electronics Material Section R

28. AN electrical connectors used in aircraft wiring systems
    a. seldom, if ever, require inspecting
    b. withstand adverse conditions much better if sealed (potted) with an approved sealing compound
    c. eliminate the need for terminal panels
    d. are used sparingly due to their prohibitive cost

29. The preferred method of attaching cable terminals to terminal blocks is by means of anchor nuts. This is advantageous because
    a. anchor nuts are always in abundance
    b. they provide an effective means of combating the effects of vibration
    c. they do not require the use of washers
    d. they require less space than types requiring lockwashers

30. The purpose of an aircraft bonding system is to
    a. eliminate the possibility of lightning damage
    b. provide noise-free radio reception
    c. obtain electrical conductivity between all metallic parts of the aircraft
    d. reduce to a minimum the wiring necessary by utilizing aircraft skin as a common ground

CHAPTER 9

AIRBORNE COMMUNICATION EQUIPMENT

As an AT, you will most likely be required to operate and maintain many different types of aircraft communication equipment. These equipments will differ in many respects; however, in other respects they will be similar. It is beyond the scope of this training course to present information that relates to all of the many different equipments; therefore, only representative sets will be discussed.

Frequency is one word that is common to almost all communication equipment. This is true because all sets operate within certain frequency limitations. It is common practice to group frequencies into bands. The so-called commercial broadcast band, extending from 535 kc. to 1,605 kc., is a familiar one. Frequency band designations and their corresponding abbreviations are shown in table 9-1.

Table 9-1.—Frequency band designations and abbreviations.

Designation of radio waves according to frequency	Authorized abbreviation	Frequency
Very low	VLF	Below 30 kc.
Low	LF	30 to 300 kc.
Medium	MF	300 to 3,000 kc.
High	HF	3 to 30 mc.
Very high	VHF	30 to 300 mc.
Ultrahigh	UHF	300 to 3,000 mc.
Superhigh	SHF	3,000 to 30,000 mc.
Extremely high	EHF	30,000 to 300,000 mc.

Among the characteristic features of airborne communication equipment are the use of automatic tuning systems, the subassembly type of construction, shock mounting of the major units, provisions for minimizing arc-over of high-potential leads when operating at high altitudes, and the use of dynamotors to supply high-voltage, d-c power.

Automatic tuning is desirable in airborne operation since the frequency changes must be made quickly and accurately. The automatic system provides for rapid selection of preset channels with great simplicity of control—usually the entire operation in channel changing is accomplished by the use of a single control dial.

The use of shock mounting results from the presence of physical shock and vibration as normal conditions in aircraft operations. The construction of the equipment in subassemblies simplifies maintenance and repair, allowing a section containing defective parts to be removed and replaced without dismantling the entire equipment.

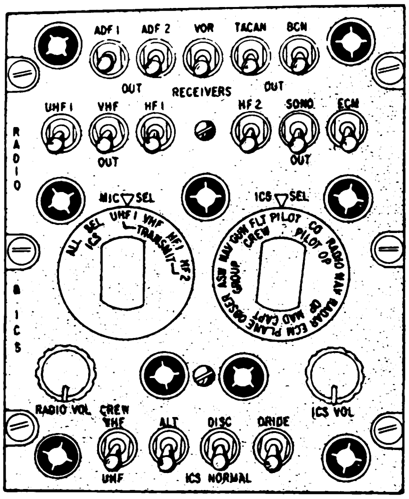
Intercommunication Equipment

All aircraft intercommunication systems perform essentially the same two functions. They deliver audio to one or several selected stations, and they provide means for radio reception and transmission from one or more stations. In other words they (1) enable the members of the crew to talk with each other; and (2) enable members of the crew to hear what is being received by the aircraft's radio receiver or receivers and to transmit messages on the aircraft's transmitter or transmitters.

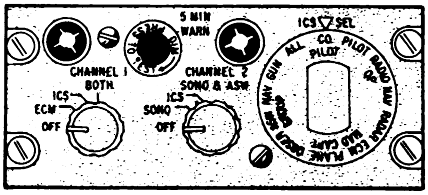
It would be impractical to discuss all of the various intercommunication systems used with naval aircraft; therefore only one representative system, the AIC-15, will be described. This system differs from most other systems in that it utilizes transistors and crystal diodes instead of vacuum tubes.

INTERCOMMUNICATION SYSTEM AIC-15

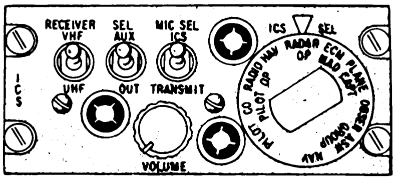
The AIC-15 intercommunication equipment (intercom for short) is designed to fulfill the requirements for a transistorized system. Within the system there are four types of station control boxes, a recorder control box, and an interconnecting box. These are shown in figure 9-1.



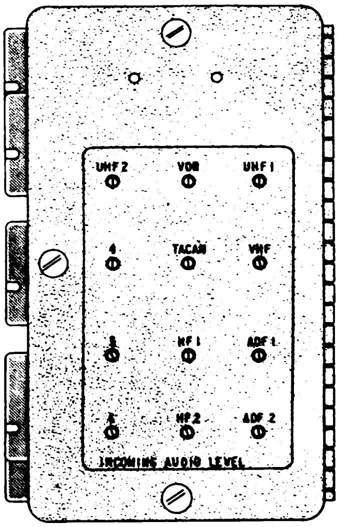
INTERPHONE CONTROL C-1908/AIC-15



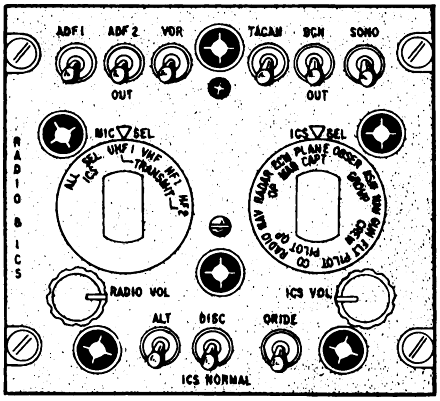
RECORDER CONTROL C-1912/AIC-15



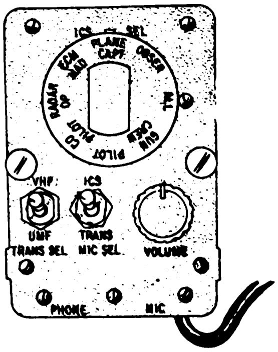
INTERPHONE CONTROL C-1910/AIC-15



INTERCONNECTING BOX J-758/AIC-15



INTERPHONE CONTROL C-1909/AIC-15



INTERPHONE CONTROL C-1911/AIC-15

Figure 9-1.—Intercommunication system AIC-15.

Although the four types of control boxes are different from one another, each type can be associated with any other type without regard to the remainder of the system so long as the number of control boxes does not exceed thirteen. The type box that is installed at a particular station is determined by the communication functions that are to be performed at that station. All boxes provide intercom and receiver facilities which are essentially equal. This system is not restricted to use with any specific radio receiver, recorder, or transmitter, but may be used with almost any radio or recording system.

Because the system's power consumption is so low, there is no ON-OFF switch as such. When the aircraft is in operation the intercom is ON; it operates from the 28-volt d-c supply.

The AIC-15 provides the following:

1. Intercommunication facilities between any number of stations from two to thirteen.
2. Provisions for listening to associated receiver audio.
3. Provisions for transmitting over associated transmitters.
4. Intercommunications on an independent and simultaneous basis between several stations or groups of stations. (More than one conversation may be carried on at the same time.)
5. Provisions for recording particular interphone and/or radio audio signals on an associated recorder.
6. Provisions for certain control units to disconnect from normally used interphone lines and to transfer these lines to an alternate control unit.
7. Provisions for an override circuit which supplies interphone audio to stations that may be in DISC (disconnect) position.
8. Provisions for supplying interphone facilities to associated jack boxes.
9. Provisions for alternate audio at certain stations by switching the headset line of those stations so that they are each connected in parallel with the audio output line of another station.

Figure 9-2 shows the basic intercom system, but it should be remembered that as many as thirteen controls (stations) may be used within the system. Also, by connecting a microphone and headset to the interconnecting box, J-758, this box may be used as an additional station.

The basic system consists of four interphone controls—C-1908 (type A), C-1909 (type C), C-1910 (type D), and C-1911 (type E)—plus the recorder control and the interconnecting box. (See fig. 9-1.) The recorder control, C-1912, is used to connect various stations to a recorder so that whatever audio is present may be recorded. This audio may be conversation on the intercom, or it may be from ECM, SONAR, ASW equipment, or a radio transmitter or receiver.

The HSI (NavAer 16-30AIC15-501) for this intercom system contains detailed procedures for operation of all units of the system. Such detailed procedure is beyond the scope of this training course; however, the pilot's and copilot's control box C-1908, will be discussed. The operation of all other control boxes, insofar as radio transmission is concerned, is controlled by this box.

Figure 9-3 shows the front view of the control box C-1908. The function of the various controls are as follows:

MIC SEL switch (1)—Connects microphone to any one of eight transmitters or to the intercommunication system.

RADIO VOL control (2)—Controls the volume of one or a number of selected radio receivers.

CREW, UHF, UHF switch (3)—Controls the access of a type C, D, or E control unit to the UHF or VHF transmitter.

ALT switch (4)—Switches headset to an alternate control unit. Used in case of a malfunction in receiving circuitry.

RECEIVER switches (5 and 10)—Connects the output of any one or combination of eleven radio receivers to the receiver amplifier circuitry.

ICS SEL switch (6)—Connects any one of twelve stations in the intercommunication system to the control unit.

ICS VOL control (7)—Controls the volume of the incoming and sidetone ICS signals.

ORIDE switch (8)—Permits overriding a DISC (disconnect), ICS NORMAL switch in the DISC position in another control unit.

DISC, ICS NORMAL switch (9)—Transfers incoming signals to another control unit.

Maintenance problems of the AIC-15 are minimized by the use of transistors and potted units. There are only a few adjustments to make when bench testing, and all such adjustments are made quickly with the proper bench test equipment. No special tools are needed to service this equipment, and a minimum of bench equipment is necessary.

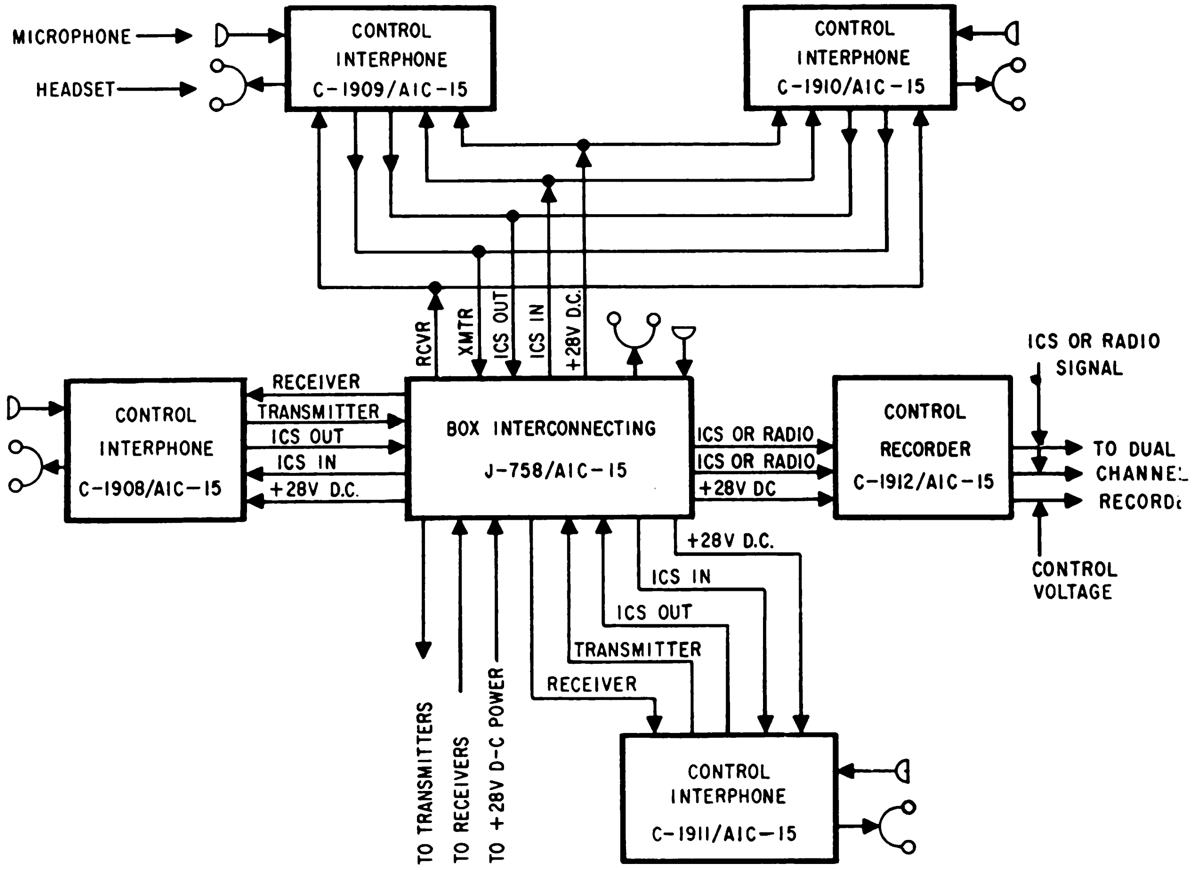


Figure 9-2.—System block diagram.

The preflight check may be made without any test equipment. As long as a control unit is able to perform satisfactorily the designated operations, the minimum performance standards are satisfied. Satisfactory performance for this intercom is to send and/or receive audio over both intercom and radio facilities with enough volume to be heard. This audio must be relatively free of noise and distortion. There should be no indication of oscillation. The system must also control the recording of selected ICS and/or radio audio.

Intercom system AIC-15 is currently in use in some naval aircraft. Its small space requirements, light weight, and dependability make it desirable from every standpoint; and its relative lack of maintenance problems makes it doubly so.

Medium- and High-Frequency Radio Equipment

RECEIVER AN/ARR-41

A receiver that finds general use in naval aircraft is the R-648; it is the main unit of Radio Receiving Set AN/ARR-41. The R-648 is a superheterodyne receiver capable of receiving RF signals from 190 to 550 kilocycles and from 2 to 25 megacycles, covered in five bands of frequencies. A countertype frequency indicator, located on the front panel of the receiver, indicates the frequency in megacycles of the received signals. Figure 9-4 shows the receiver and its various controls.

The function of the various controls are as follows:

POWER (1)—Primary power off-on control.
EMISSION (2) (CAL)—Connects frequency calibration circuitry.
(VOICE)—Connects broadband (914 kilocycle) filter for radiotelephone reception.

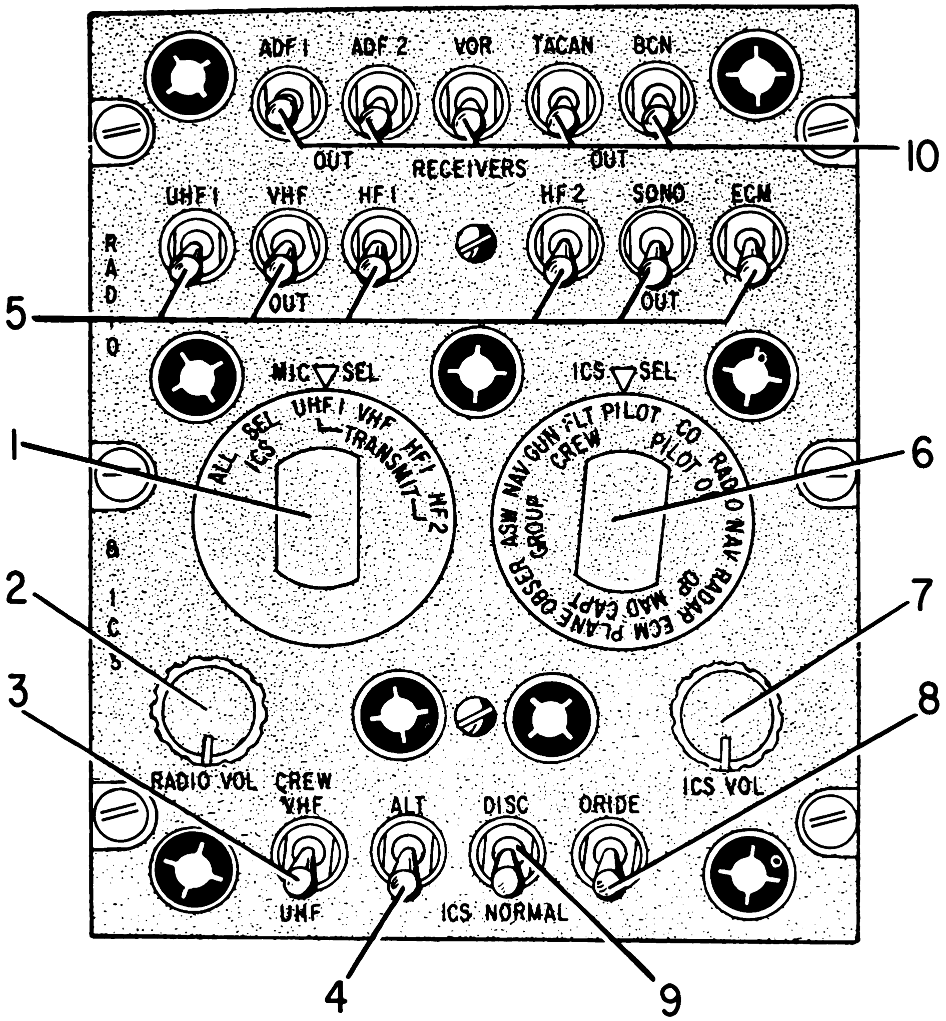


Figure 9-3.—Pilot and co-pilot control box C-1908.

1. MIC SEL switch.
2. RADIO VOL control.
3. CREW, VHF, UHF switch.
4. ALT switch.
5 and 10. RECEIVER switches.
6. ICS SEL switch.
7. ICS VOL control.
8. ORIDE switch.
9. DISC, ICS NORMAL switch.

(VOICE SHP)—Connects narrow-band (1.4 kilocycle) filter for radiotelephone reception. (SHP—sharp reception)

(CW)—Connects broad-band (6.0 kilocycles) filter for CW reception.

(CW SHP)—Connects narrow-band (1.4 kilocycle) filter for CW reception.

BANDSWITCH (3)—Selects frequency of reception in one-megacycle steps.

TUNING (4)—Tunes the receiver throughout a one-megacycle increment.

DIAL LOCK (5)—Locks the TUNING control at a desired setting.

GAIN (6)—Controls sensitivity.

SENS ADJ (7)—Vernier sensitivity adjustment.

BFO (8)—Controls tone of beat signal during CW reception.

DIAL ZERO (9)—Sets MEGACYCLES frequency indicator for calibration.

MEGACYCLES (10)—Indicates frequency in megacycles.

PHONES (11)—Connector for headset.

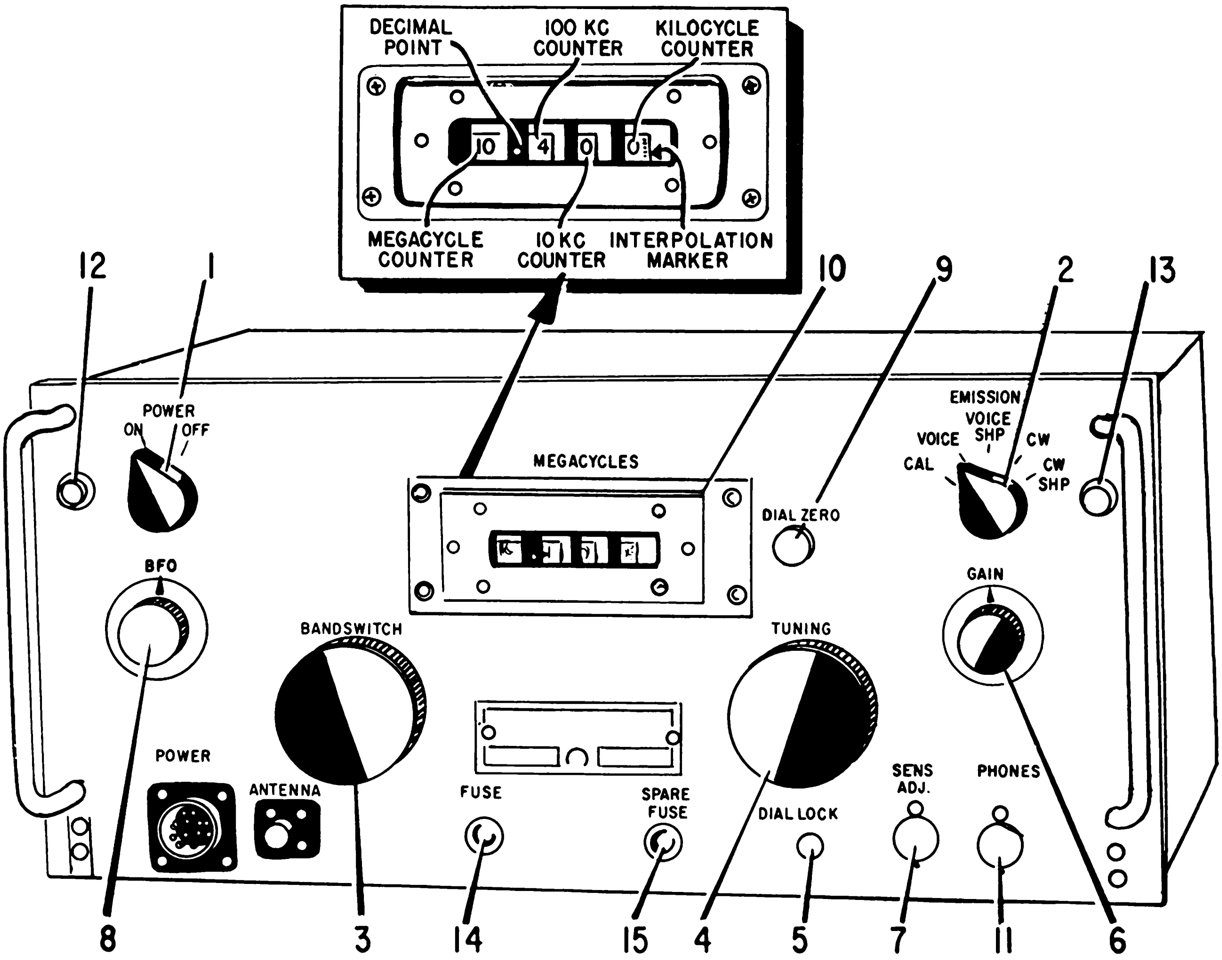


Figure 9-4.—Radio receiver R-648/ARR-41.

1. POWER.
2. EMISSION.
3. BANDSWITCH.
4. TUNING.
5. DIAL LOCK.
6. GAIN.
7. SENS ADJ.
8. BFO.
9. DIAL ZERO.
10. MEGACYCLES.
11. PHONES.
12. LOCK.
13. LOCK.
14. FUSE.
15. SPARE FUSE.

LOCK (12, 13)—Locks the front panel to the chassis.

FUSE (14)—Overload protection.

SPARE FUSE (15)—Replacement.

The R-648 is capable of receiving amplitude-modulated signals, unmodulated CW, and also frequency-shift-keyed radioteletype when an external converter is employed for operation of the printer. Accurate frequency calibration is obtained through a built-in circuit consisting of a 500-kilocycle crystal-controlled oscillator and a multivibrator.

Like most aircraft electronic equipment being manufactured, the ARR-41 is of modular and subassembly design. Maintenance and troubleshooting are simplified because the technician performing corrective maintenance can readily and easily replace a suspected subassembly with a good one, thereby quickly locating the source of trouble.

Some of the test equipment used in maintenance of this receiver are discussed in this training course; for example, the TV-7 tube tester, the URM-25 RF signal generator, and the TS-505 VTVM. A complete list of necessary test equipment appears in the HSI for the receiver (NavAer 16-30ARR41-502). The HSI also presents in detail the theory and operation of the receiver, as well as maintenance, test, and alinement procedures. Only a brief description of the theory of the R-648 will be presented in this chapter.

Theory of Operation

This receiver employs double conversion. That is, all received RF signals, except for band 2, are first converted to a variable (2-4 megacycles) IF frequency, amplified, and then converted to a fixed frequency of 500 kilocycles. (Channel 2 covers the range of 2 to 4 megacycles, so signals on this channel are shunted around the first converter, or mixer.) Some of the benefits obtained by double conversion are high gain and sensitivity.

For CW (continuous wave) reception the set employs a BFO (beat-frequency oscillator), with a control for variable pitch or tone. A CW signal contains no modulation, so a separate oscillator must be built into the receiver in order to receive CW. The principle of the BFO is discussed in *Basic Electronics*, NavPers 10087.

Figure 9-5 is a block diagram of the receiver. Reference to this diagram, in connection with the discussion that follows, will simplify the explanation of the operation of the receiver—pay particular attention to the direction of the arrows.

The incoming RF signal is received by the antenna and applied to one of five tuned circuits, depending upon the band of reception. The signal is then applied to the grid of the first RF amplifier, *V*701, for amplification. After the first stage of RF amplification, frequencies within the range of bands 1, 3, 4, and

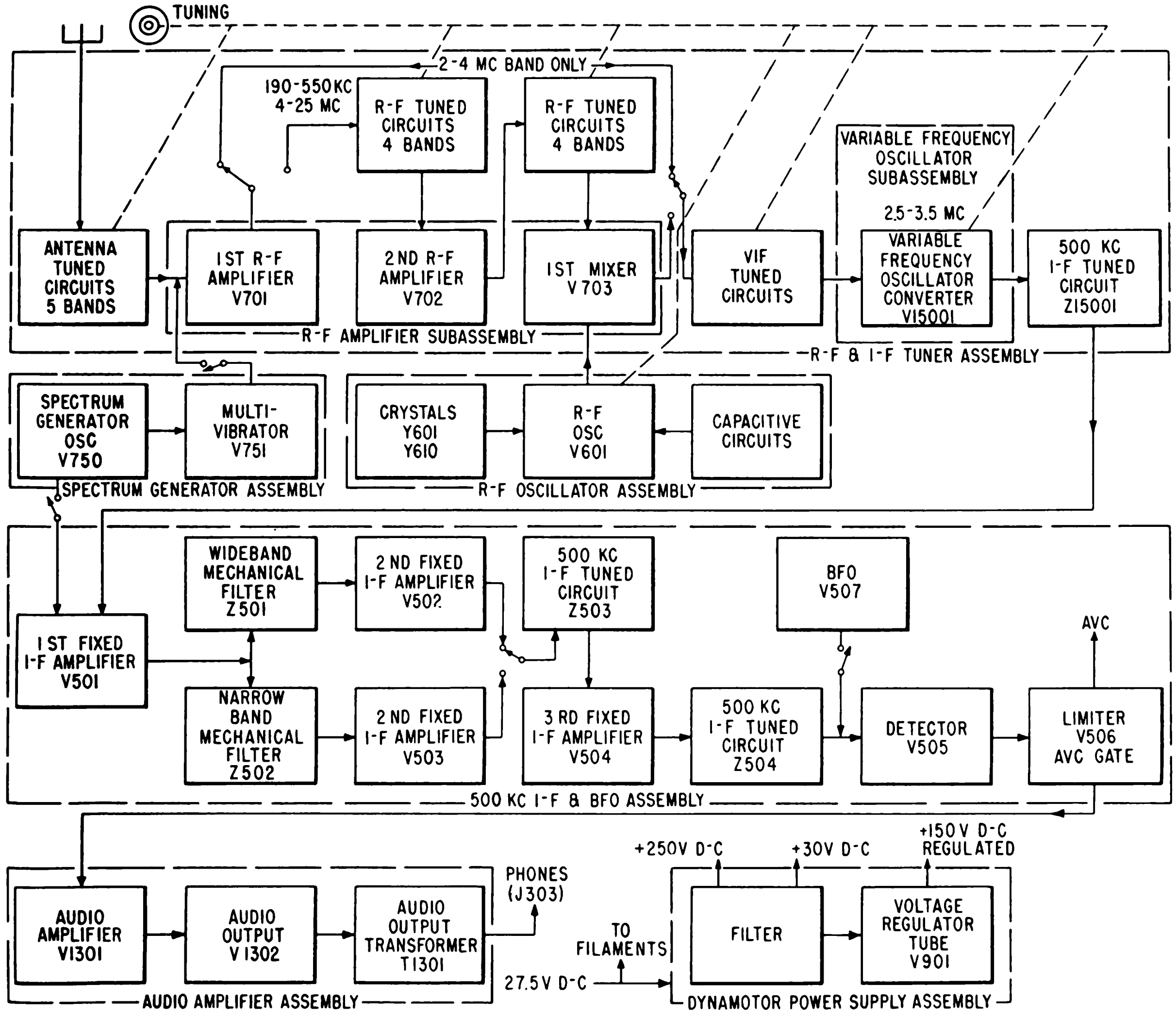

TUNING
2-4 MC BAND ONLY
190-550KC
4-25 MC
R-F TUNED CIRCUITS 4 BANDS
R-F TUNED CIRCUITS 4 BANDS
VARIABLE FREQUENCY OSCILLATOR SUBASSEMBLY
2.5-3.5 MC
ANTENNA TUNED CIRCUITS 5 BANDS
1ST R-F AMPLIFIER V701
2ND R-F AMPLIFIER V702
1ST MIXER V703
VIF TUNED CIRCUITS
VARIABLE FREQUENCY OSCILLATOR CONVERTER V15001
500 KC I-F TUNED CIRCUIT Z15001
R-F AMPLIFIER SUBASSEMBLY
R-F & I-F TUNER ASSEMBLY
SPECTRUM GENERATOR OSC V750
MULTI-VIBRATOR V751
SPECTRUM GENERATOR ASSEMBLY
CRYSTALS Y601 Y610
R-F OSC V601
CAPACITIVE CIRCUITS
R-F OSCILLATOR ASSEMBLY
WIDEBAND MECHANICAL FILTER Z501
2ND FIXED I-F AMPLIFIER V502
500 KC I-F TUNED CIRCUIT Z503
BFO V507
AVC
1ST FIXED I-F AMPLIFIER V501
NARROW BAND MECHANICAL FILTER Z502
2ND FIXED I-F AMPLIFIER V503
3RD FIXED I-F AMPLIFIER V504
500 KC I-F TUNED CIRCUIT Z504
DETECTOR V505
LIMITER V506 AVC GATE
500 KC I-F & BFO ASSEMBLY
+250V D-C
+30V D-C
+150V D-C REGULATED
AUDIO AMPLIFIER V1301
AUDIO OUTPUT V1302
AUDIO OUTPUT TRANSFORMER T1301
PHONES (J303)
TO FILAMENTS
27.5V D-C
FILTER
VOLTAGE REGULATOR TUBE V901
AUDIO AMPLIFIER ASSEMBLY
DYNAMOTOR POWER SUPPLY ASSEMBLY

Figure 9-5.—Block diagram of radio receiver R-648.

5 are applied through tuned circuits to the second RF amplifier and then through more tuned circuits to the first mixer, *V*703. The function of the first mixer is to heterodyne the output of the RF oscillator, *V*601, with the incoming RF and produce a variable IF of 2 to 4 megacycles. Band 2 frequencies are 2 to 4 megacycles without heterodyning and therefore are switched around the second RF amplifier and first mixer circuits. The switches in the block diagram are shown in band 2 position. All bands of frequencies are now within the range of 2 to 4 megacycles and are applied through the variable intermediate frequency-tuned circuits to the variable frequency oscillator converter, *V*15001. Mixer *V*15001 heterodynes the incoming 2- to 4-megacycle signal with a locally generated 2.5- to 3.5-megacycle signal, producing an output of 500 kilocycles, the fixed IF frequency.

The 500-kilocycle signal is applied to the grid of *V*501 for first IF amplification. This output passes through either a broad- or narrow-band special type mechanical filter (fully explained in chapter 10 in connection with single sideband (SSB)) depending upon the setting of the EMISSION switch, and through one of two second IF amplifiers. The IF signal is then applied through another tuned circuit to the grid of the third IF amplifier, *V*504, the plate circuit of which contains the IF tuned circuit *Z*504. Tuned circuit *Z*504 couples the output of IF amplifier *V*504 to the detector tube *V*505. The functions of *V*505 are to recover the modulation component of the IF signal (detection) and to produce a negative voltage proportional to the carrier level for automatic volume control (avc).

The BFO may be switched into the detector input by operation of the EMISSION switch to the CW or CW SHP positions. In this manner a beat note is produced with the 500-kilocycle IF signal, which is a variable tone to be used for CW reception. Output from the detector is applied to *V*506, the limiter, and avc gate. One-half of dual diode, *V*506, functions as an avc gate control and prevents application of avc voltage to the various amplifiers until full receiver sensitivity has been reached. The other half of *V*506 is a noise limiter which suppresses undesired noise pulses. The output of *V*506 is an audio voltage proportional to the modulation of the incoming RF signal. Audio amplifier *V*1301 and audio output *V*1302 serve to amplify the audio signal. Phone jack *J*303 is connected to audio output transformer *T*1301, and is available on the front panel of the receiver.

The spectrum generator consists of a crystal-controlled oscillator and a multivibrator divider circuit. The crystal-controlled oscillator, *V*750, serves to produce an accurate 500-kilocycle signal. The 500-kilocycle signal is applied to the grid of the first IF amplifier, *V*501, and to one plate and grid of the multivibrator divider, *V*751. The multivibrator fires on every fifth input pulse and produces an output to the first RF amplifier of 100 kilocycles. This 100-kilocycle frequency is rich in harmonics and allows the RF circuits to be tuned to a particular harmonic, depending upon the resonant frequency of the tuned circuits. A beat note is produced as a result of heterodyning the 500-kilocycle signal applied to the first IF amplifier with the selected harmonic of the multivibrator. This beat note is heard when the receiver frequency is varied around the selected multivibrator harmonic and the correct receiver frequency is known on the basis of the counter reading. The counter may then be set to the exact 100-kilocycle multiple and calibration is completed.

The dynamotor power supply serves to convert the 27.5-volt d-c source voltage into a usable output for the screens and plates. The necessary filter and divider circuits are employed to produce a 250-volt d-c supply, a 150-volt regulated d-c supply, and a 30-volt d-c supply for avc delay bias.

Operation

After having studied figure 9-4 and the functions of the various controls, you should have a general understanding of how to operate the receiver. Additional information that relates to receiver operation will now be given.

The EMISSION switch (2) has two positions that indicate NOISE SHP and CW SHP. These positions are used when noise interferes with reception on the VOICE or CW positions. The SHP position switches a narrow-band filter into the IF circuit which reduces the noise level.

Frequency is read on the MEGACYCLES counter (10). The BANDSWITCH (3) selects the desired megacycle frequency which is read on the "left" dial of the megacycle counter. The TUNING control (4) operates the three "right-hand" counter wheels for frequencies less than one megacycle. Interpolation to within 0.1 kilocycle is possible with the use of the arrow located at the right of the right-hand counter wheel.

Calibration

Calibration of this receiver is relatively simple. First, operate the BANDSWITCH (3) to the megacycle frequency on which calibration is desired. (See fig. 9-4.) The megacycle frequency is indicated by the left-hand counter wheel of the MEGACYCLES frequency indicator (10).

Next, operate the TUNING control (4) to the 100-kilocycle check point nearest the desired calibration frequency. This is indicated by the second counter from the left-hand side of the indicator. For example, assume calibration is desired at the check point nearest the frequency of 10.440 megacycles. The BANDSWITCH (3) and TUNING control (4) should be operated for a reading of 10.400 on the MEGACYCLES frequency indicator (10).

Rock the TUNING control slowly around the check point frequency until a zero beat is obtained in the headset. Depress the DIAL ZERO knob (9) and rotate until the reading on the MEGACYCLES frequency indicator corresponds to the nearest checkpoint frequency. In the example used, this would be 10.400 megacycles.

AUTOTUNE TRANSMITTER AN/ART-13

This transmitter has been in use in naval aviation for many years, and it is still an excellent radio transmitting set in its frequency range. It features high power output, an autotune system with eleven preset channels, and three types of emission. The transmitter, which provides radio communications by means of CW, MCW, or VOICE types of emission, is shown in figure 9-6.

Transmissions can be made on any one of eleven preset frequencies. Rapid changes in operating frequency are made possible by the use of an automatic tuning mechanism called the autotune system. With this system, variable tuning inductors, variable tuning capacitors, and switches are positioned automatically by mechanical means. The mechanical system is controlled electrically either from the transmitter panel, the pilot's control unit, or other remote control units. The accuracy with which the autotune system adjusts the frequency-setting elements is of a very high order. The frequency adjustments are not affected by wear of the mechanical parts, by humidity, or by changes in temperature.

One of the eleven autotune positions is used for low-frequency operation in the range from 200 to 1,500 kc. provided a low-frequency

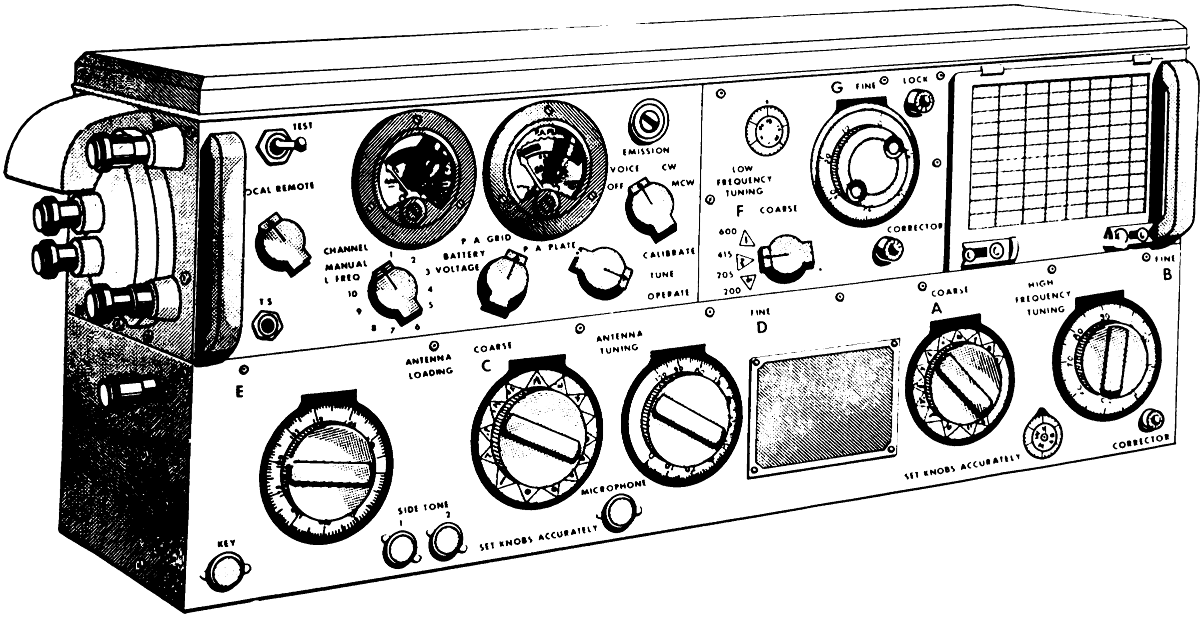


Figure 9-6.—Transmitter unit T-47/ART-13.

oscillator unit (O-16/ART-13) is installed in the transmitter and external loading coils and a trailing wire antenna are used.

Operating and Electrical Characteristics

The transmitter shown in figure 9-6 is designed to operate with a 28-volt, d-c power source. Voltage as low as 24 volts may be used in emergency operation, but this results in lowered output power and in longer operating time for the autotune system, which normally requires less than 25 seconds for a complete cycle.

The d-c power source must be capable of supplying an average current of about 35 amperes and surge currents up to 50 amperes.

When operated at altitudes above 25,000 feet, a relay in the transmitter control circuit is activated because of decreased atmospheric pressure. The action of the relay reduces the plate voltage on the power amplifier and the modulator tubes to prevent arc-over. The reduction in plate voltage results in an output power of about one-half that produced with full voltage.

The primary power required for each type of operation is as follows:

Type of Emission	Full Power	Half Power
CW.	770 watts. .	658 watts.
MCW	855 watts. .	700 watts.
VOICE (Unmodulated)	800 watts. .	672 watts.
VOICE (Modulated) . .	896 watts. .	700 watts.

The output power derived from the transmitter varies with the frequency of operation and ranges from about 5.5 watts at 200 kc. to 90 watts at frequencies from 5.5 megacycles to 13.5 megacycles.

Two ranges of operating frequencies are provided. The low-frequency range extends from 200 kc. to 1,500 kc. The high-frequency range extends from 2 to 18.1 megacycles. The output falls off for the higher frequencies to approximately 6.5 watts at 18.1 mc.

Major Components of the AN/ART-13

The major components of the AN/ART-13 equipment consists of the transmitter (T-47/ART-13), a dynamotor (DY-12/ART-13), the pilot's control unit, and the antenna shunt capacitor (CU-24/ART-13).

The dynamotor supplies d-c voltages for the screen and plate circuits of the transmitter. It contains an armature equipped with dual windings and two commutators which provide two voltages, 400 and 750. These two values are combined to supply plate voltage for the power amplifier and the modulator tubes.

The operating channel and the type of emission are selected and controlled at the transmitter panel, from remote control units, or from the pilot's control unit. One model of the pilot's control unit is illustrated in figure 9-7.

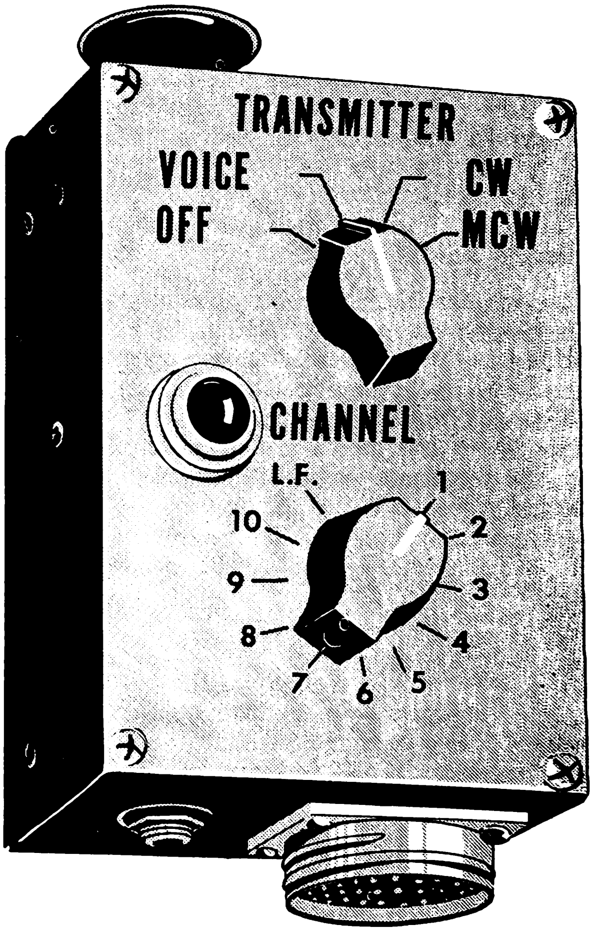


Figure 9-7.—Pilot's control unit.

An antenna shunt capacitor is used when the equipment is operated in the 2,000 to 3,000 kc. range if the antenna in use does not have sufficient capacitance to permit tuning the output circuit to resonance.

Two loading coil units are available with the equipment and are used in the 200 to 500 kc. and the 500 to 1,500 kc. ranges.

Microphone Circuit

The audio input circuit of the AN/ART-13 transmitter is designed to match either a carbon or a dynamic microphone. The proper input circuit for the type of microphone in use is selected by means of a switch. In the CARBON position of the switch, provision is made for matching a microphone of about 40 ohms internal resistance; in the DYNAMIC position, the input circuit matches a dynamic microphone of about 200 ohms internal resistance.

Modulation

Class B modulation is used. The modulators are operated in push-pull and are capable of supplying sufficient audiofrequency power to modulate the RF carrier up to 90 percent when operating with voice emission.

General Theory of Operation

The transmitter consists of three major sections: the radiofrequency section, the audio system, and the crystal frequency indicator (calibration) section. The stages included in these sections are shown in block diagram form in figure 9-8.

1. RADIOFREQUENCY SECTION. The RF signal is initiated in either a high-frequency or a low-frequency oscillator. The high-frequency oscillator is used when the transmitter is operated in the 2- to 18.1-mc. range. The low-frequency oscillator unit is employed during operation on frequencies between 200 and 1,500 kilocycles.

The high-frequency oscillator generates signals in the frequency range from 1,000 to 1,510 kc. This range is covered in two bands, 1,000 to 1,200 kc. and 1,200 to 1,510 kc. The band in use is determined by the position of a switch which is operated by means of the course frequency tuning adjustment of the control panel. Fine frequency adjustments are made within each band by varying the setting of a fine frequency control knob which sets the inductance values in the oscillator tuning circuits.

In low-frequency operation of the transmitter, the output of the low-frequency oscillator is applied to the input of the final amplifier stage with no frequency multiplication. When the equipment is operated in the high-frequency range, the output of the high-frequency oscillator is multiplied in frequency before amplification by the final power amplifier.

Two frequency multiplier stages are used. The first multiplier may be operated as a frequency doubler, as a tripler, or as a quadrupler. The second multiplier functions only as a tripler. By means of the various combinations of multiplication thus provided, the output frequency of the oscillator can be increased from two to twelve times, giving a frequency range of 2 to 18.1 mc.

The amount of multiplication in effect is determined by the setting of the course frequency control knob (Control A, fig. 9-6) on the transmitter panel. Control A has twelve high-frequency positions. In the first six positions the output of the first multiplier is connected to the grid of the power amplifier tube and the second multiplier stage is inoperative. In the last six positions of the control knob, both multiplier stages are in operation. (Multiplier selection is symbolized in fig. 9-8 by means of a switch.)

The final stage provides no frequency multiplication, but operates as a straight-through amplifier on all operating frequencies. Its plate voltage is 1,150 volts except when operating at high altitudes when the action of the pressure-operated relay causes the plate potential to be reduced to 750 volts. Grid and plate current in the power amplifier tube may be measured by means of a meter located on the transmitter panel. The meter is placed in the circuit to be measured by means of a selector switch, and is used when tuning the transmitter.

The output of the power amplifier tube is capacitively coupled to the plate tuning circuit and to the antenna coupling, or loading, network. The coupling network is connected either as a pi or an L section, depending on the setting of a switch which governs the arrangement of the capacitors and inductors in the network. By means of these arrangements, the coupling circuit provides for matching the plate circuit impedance to the impedance of typical aircraft antennas when operating at frequencies from 3 to 18.1 mc. When operating between 2 and 3 mc., a shunt antenna capacitor is provided for tuning the antenna to resonance. The capacitor (Type CU-24/ART-13) is connected across the terminals of the coupling network.

2. CRYSTAL FREQUENCY INDICATOR SYSTEM. The transmitter contains an internal calibration system, generally referred to as the crystal frequency indicator (CFI). (See

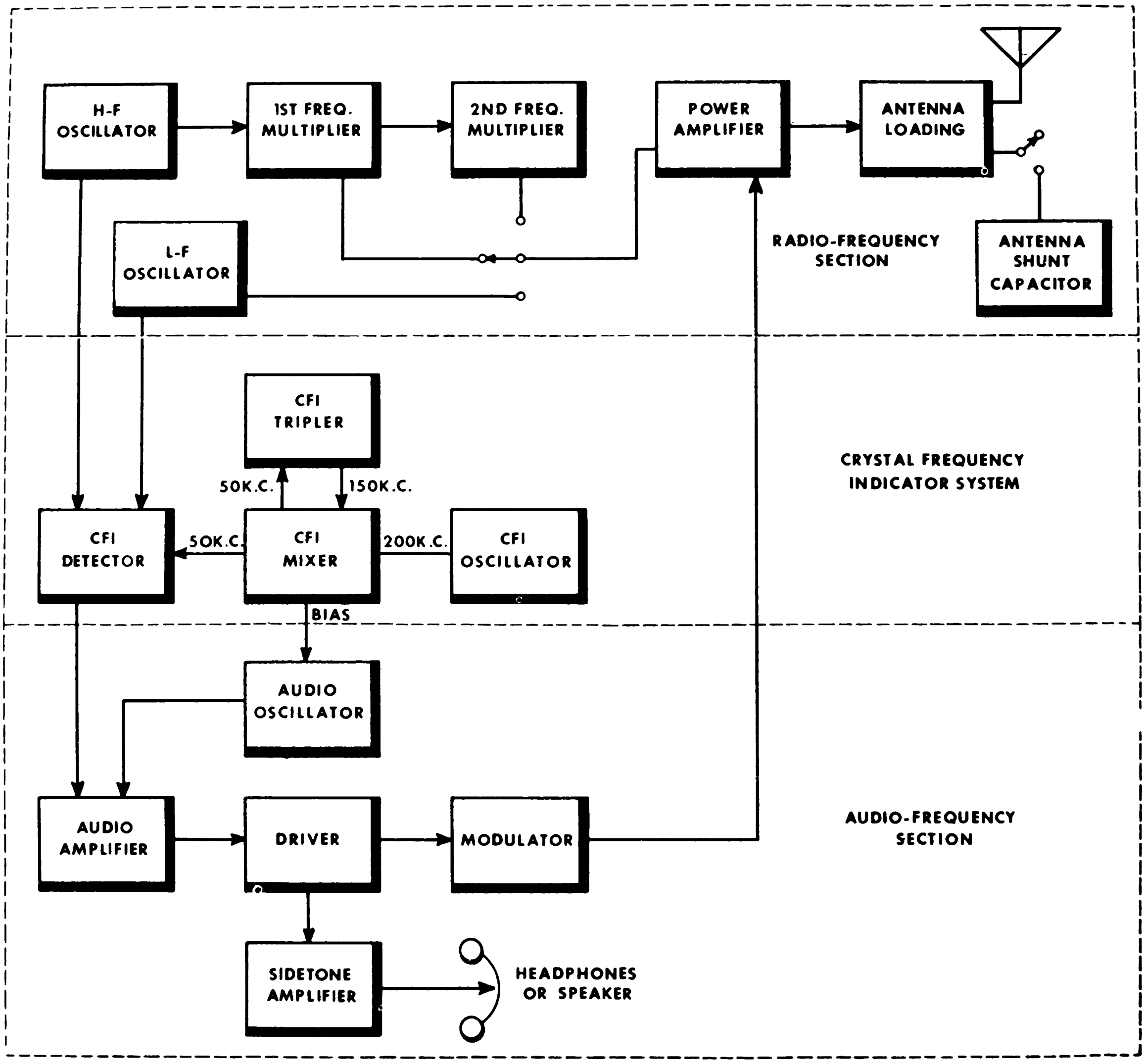


Figure 9-8.—Block diagram, T-47/ART-13.

fig. 9-8.) The CFI circuits produce a 50-kilocycle signal with many harmonics, or multiples, of 50 kc. The harmonics are used as standard signals for calibrating the frequency control dials so that the dial settings correspond to actual values of operating frequency. The 50-kc. signal and the harmonic frequencies are controlled by a crystal oscillator which insures accuracy in the standard frequency values.

The circuits which produce the calibration signals are shown in simplifier schematic form in figure 9-9.

The CFI oscillator, tripler, and mixer circuits form a regenerative frequency divider, which develops a 50-kc. output under the control of the 200-kc. crystal.

The 200-kc. output signal from the oscillator is coupled to the injector grid (*G*1) of the CFI mixer tube. When voltage is first applied to the circuits, the plate circuit of the mixer tube contains many frequency components, some of which are caused by random noise voltages. The mixer plate circuit is tuned to 50 kc. and this component of the random noise frequencies is selected by the tuning circuit and applied to the grid of the CFI tripler, *V*2201A. The tripler tube is one section of a twin-triode. The plate circuit of the tripler is tuned to 150 kc., the third harmonic of the 50-kc. input signal. The 150-kc. signal

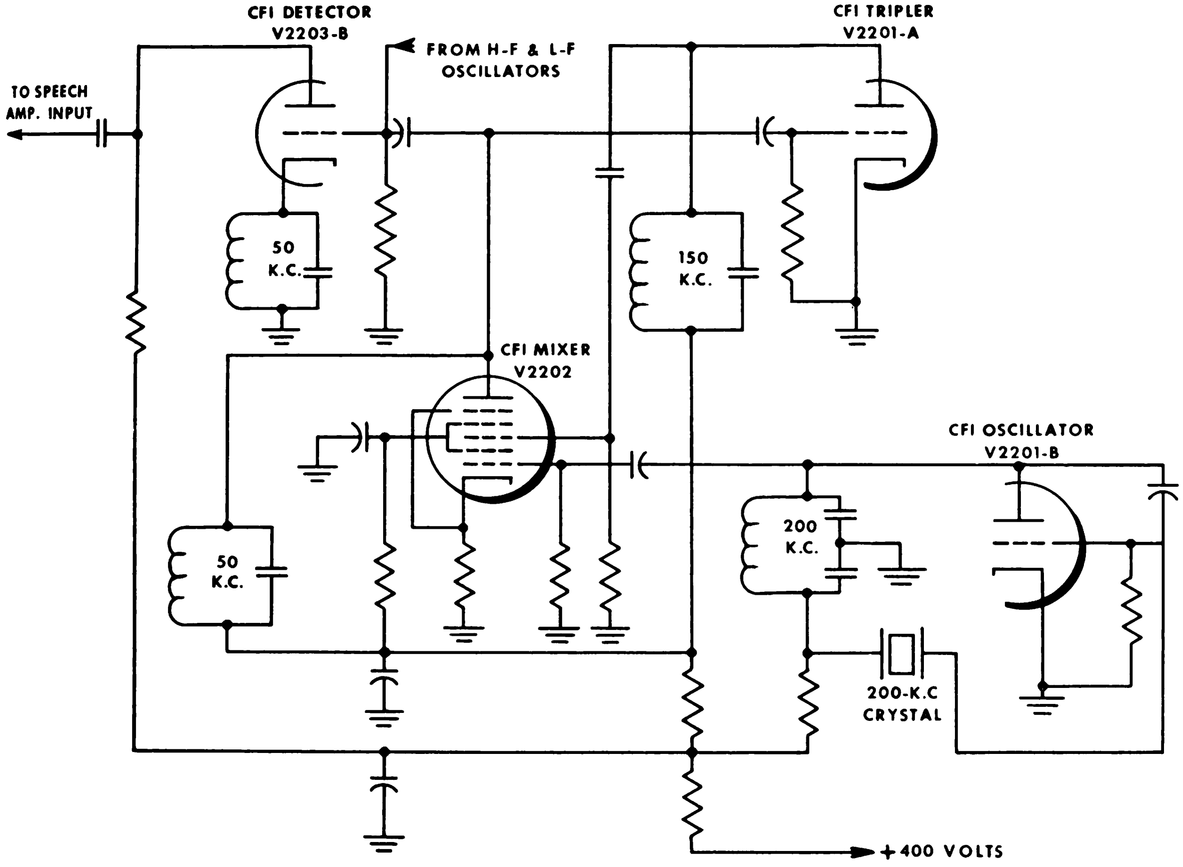


Figure 9-9.—Simplified schematic diagram of the CFI circuits.

developed in the plate circuit of the tripler is coupled back into the signal grid (*G*3) of the mixer tube, *V*2202.

As a result of this action, the electron stream comprising the plate current in the mixer tube is controlled by two signals, the 200-kc. output of the crystal oscillator and the 150-kc. output of the tripler. The difference frequency resulting from mixing these two voltages appears as a strong 50-kc. component in the mixer plate circuit which sustains the oscillation in the mixer tuning circuit.

The 50-kc. mixer output is coupled to the grid of the CFI detector, *V*2203B, one section of a twin-triode tube. The detector circuit produces many harmonics of 50-kc. When, in addition to the mixer output, a signal from either the low-frequency or high-frequency oscillator is applied to the detector, audible beat frequencies are produced in the detector every 50 kilocycles as the oscillator is tuned across the operating range. The beat frequencies are difference frequencies between the oscillator signal and the harmonic nearest it in frequency. The audible frequencies are coupled to the input of the speech amplifier and can be heard in the headphones in the output of the sidetone amplifier. When the oscillator is adjusted to give zero beat with a harmonic, the oscillator frequency is equal to the harmonic frequency.

During calibration of the control dials, the oscillator is adjusted to the value of the check frequency and the control dials are then set to the reading corresponding to the known frequency.

One section of the twin-triode tube which contains the CFI detector is used as an audio oscillator tube. The audio oscillator supplies a 1,000-cycle voltage which is employed for monitoring the keying in CW operation and for modulating the carrier in MCW operation. The oscillator has no function in the CFI circuits but is controlled by means of a cathode bias resistor common to the audio oscillator and the CFI mixer. When the CFI circuits are being used for calibration, the mixer tube is operative and draws considerable cathode current through the common resistor. The current is sufficient to develop cutoff bias for the oscillator tube. This prevents the oscillator from applying 1,000-cycle energy to the CFI detector where such a signal would affect the calibrating signals.

When the CFI unit is not in use, the bias developed across the common resistor is low, thus allowing the oscillator to operate. An inoperative CFI oscillator results in the production of a constant 1,000-cycle tone.

3. AUDIOFREQUENCY SYSTEM. The audio system consists of an audio speech amplifier, a driver amplifier, a push-pull modulator stage, a sidetone amplifier, and an MCW audio oscillator. (See fig. 9-8.)

Either a carbon or a dynamic microphone may be used in the input circuit of the first audio amplifier. Transformer coupling is employed between microphone and grid circuit. The amplifier circuit contains a pentode, the output of which is coupled through an R-C coupling circuit to the grid of an audio driver tube.

The output of the driver is applied both to the modulator grids by transformer coupling and to the input of the sidetone amplifier by means of R-C coupling.

The modulator consists of two triodes connected in push-pull. The audio output of the modulator tubes is applied to both the screen and the plate of the final RF amplifier through a modulation transformer. The output audio power developed is sufficient for modulating the RF carrier up to 90 percent with full voltage applied to the power amplifier plate.

The normal plate potential of the modulator tubes is 1,150 volts. This value is reduced to 750 volts by the action of the pressure-actuated relay during operation at high altitudes.

When the transmitter is operated in CW emission, the modulator stage is inoperative. The plate voltage is removed from the tubes and the section of the modulation transformer attached to the power amplifier plate is shorted by the action of a relay.

The sidetone amplifier provides the operator with a means of monitoring voice signals, CW-MCW keying, or the audio tone generated by the audio oscillator. A portion of the output of the audio driver amplifier is fed into the grid of the sidetone amplifier. The output of the stage is coupled through a matching transformer either to headphones or to a speaker. This output circuit is keyed by the operation of the keying relay during CW transmission.

AN/ARC-2 TRANSCEIVER

Transmitters and receivers are often contained within a single case, and are called transceivers. Normally, with such an arrangement, both the transmitter and receiver are tuned simultaneously to the same frequency, often by remote control boxes. They also utilize the same power supply, and very often the same frequency controlling crystals or oscillators.

The AN/ARC-2 is a radio communication set designed for installation in all types of naval aircraft. It provides reliable, preset, two-way radio communication, using CW, MCW, or voice. Communication may be controlled from any one of several control boxes, and provision is made for rapid selection among eight preset channels. Frequency coverage of this transceiver is from 2 to 9.05 megacycles, essentially in the high-frequency range.

Figure 9-10 shows the front panels of the ARC-2 and ARC-2A. Note that the only difference between them is the addition of fuse holders and the omission of the meter switch on the ARC-2A. The transmitting and receiving functions of these two transceivers are identical. The transmitters differ only in mechanical detail and in the milliammeter circuit.

The transmitter and receiver circuits are tuned by a common set of controls. Some of the circuits thus controlled are common to both the transmitter and the receiver. The transmitter provides CW, MCW, and amplitude-modulated voice emission. The receiver employs a superheterodyne circuit, and will receive CW, MCW, and amplitude-modulated signals.

A feature of this radio set is the circuit arrangement which makes possible either transmission or reception on the same frequency, with the adjustment of one common set of controls. This is accomplished by using one variable-frequency oscillator to provide transmitter frequency control and to excite the receiver mixer tube. The controls are tuned to the desired frequency for either transmission or reception by the same autotune system. Another common circuit is composed of both the antenna tuning network and the power-amplifier plate tank circuit. It is used to couple both transmitter and receiver to the antenna. The ARC-2 employs a unique system of variable

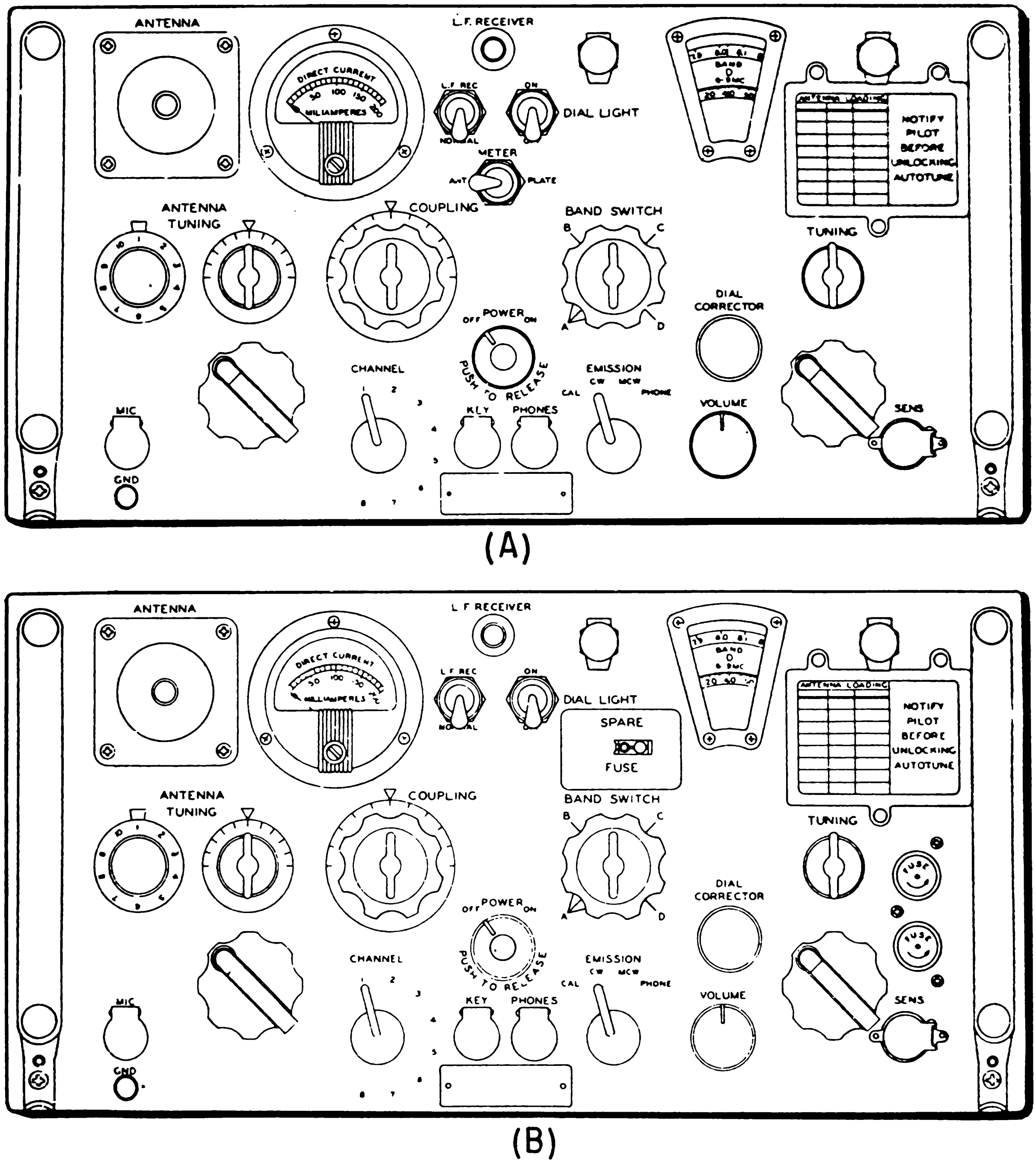


Figure 9-10.—(A) Transmitter-receiver RT-91/ARC-2, front panel; (B) transmitter-receiver RT-298/ARC-2A, front panel.

IF amplifiers. Their frequency varies between 1 and 1.5 mc. The use of variable IF amplifiers with the common master oscillator makes this equipment unusual in its frequency range.

Control Boxes

Figure 9-11 shows the various control boxes that may be used with the ARC-2. All perform essentially the same functions of turning the power on and off, and selecting any one of eight channels. Control box C-732A also employs a SENS control for controlling receiver sensitivity when receiving CW or MCW.

Operation

The EMISSION switch selects the type of emission desired—CW, MCW, or voice. It can only be operated from the front panel. If the transceiver front panel is not accessible during flight, the type of transmission must be selected before takeoff.

Setting frequencies on selected channels and tuning the ARC-2 are relatively simple operations. The HSI gives detailed procedures, and it is important that these be followed. During this operation the controls on the autotune knobs must be unlocked. Care must be taken to prevent operating the channel selector while the controls are unlocked. Operating the autotune with controls unlocked will erase the settings of all channels.

Transmission is accomplished by selecting the desired channel and by actuating the switch to be used to control transmission. This switch may be a microphone switch, a throttle switch, or a key. For reception on the same frequency merely release the switch actuated for transmission.

Turning off the Equipment

The set may be turned off by positioning the last operated OFF-ON control to OFF. Remember, ONLY the power switch operated LAST will turn off the set.

When operation is being controlled from the front panel, press the POWER OFF-ON switch inward to turn off the set.

When operation is being controlled from control boxes C-244A, C-245A, or C-732A, turn the locking lever counterclockwise and simultaneously press inward on the OFF-ON control to turn off the equipment. Caution: Do not attempt to force the OFF-ON controls to the OFF position by manual rotation. Pressing inward on the OFF-ON control is all that is required to turn off the set.

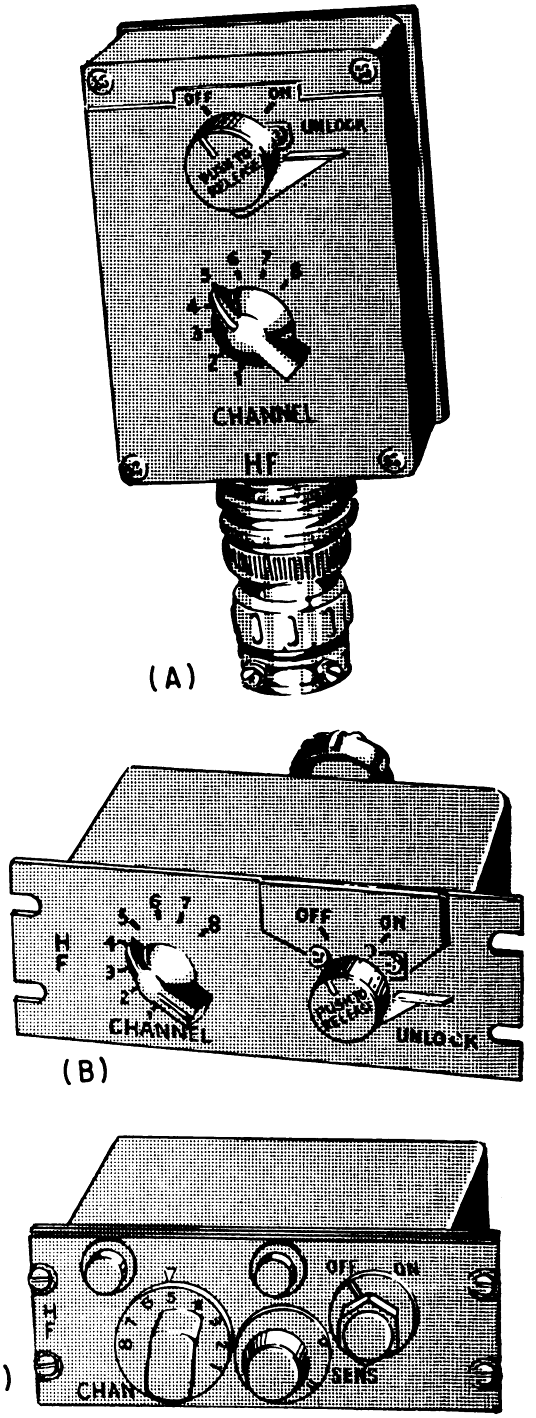


Figure 9-11.—(A) Control box C-244A; (B) control box C-245A; and (C) control box C-732A.

When control box C-732A is controlling operations, rotate the OFF-ON switch counterclockwise to turn off the set.

Sensitivity Adjustment

Located on the front panel of the ARC-2 is a SENS adjustment. This adjustment sets the permissible noise level of the receiver. It is to be made with the aircraft engine running. A regular screwdriver is required, and, of course, headphones.

With the aircraft engine running and the transceiver warmed up to operating temperature, turn the EMISSION selector to PHONE. Before making the sensitivity adjustment detune the receiver so that no signal is being received. Turn the volume control to full volume and with the screwdriver adjust the SENS to the maximum tolerable noise level. If the noise level is not loud enough to cause discomfort at any setting of the SENS control, the control should be rotated to the full-on (extreme clockwise) position.

Block Diagram

Figure 9-12 is a functional block diagram of radio sets ARC-2 and ARC-2A. By referring to this diagram the operation of the sets may be more easily understood.

The use of a single master oscillator for both the transmitter and receiver, in addition to the variable-tuned IF circuits, makes this equipment unusual in its frequency range. The master oscillator is in operation whenever power is applied to the set, and its output is applied through frequency multipliers to the receiver and transmitter, but is cut off from the transmitter when the receiver is in use. A noise limiter and an audio limiter in the receiver improve performance by decreasing the amplification of noise pulses and very strong signals which would ordinarily cause overloading and distortion in the output stage. Likewise, an audio limiter and limiter control in the transmitter prevent overmodulation of the carrier. A positive check of overall transmitter operation is provided by a sidetone taken from the antenna-matching network. Another feature is a built-in crystal-frequency indicator, which provides a means for accurately setting the equipment to any predetermined frequency in the range from 2 to 9.05 mc. This is particularly necessary, since a pretuned receiver or transmitter cannot be adjusted by the pilot during flight.

Special effort has also been made in the design of the equipment to prevent interference with other equipment. In addition to careful shielding, all power, audio, and control circuits are provided with individual choke-capacitor filters, which effectively isolate the circuits inside the transmitter-receiver from those outside. Arrangements have also been incorporated for monitoring low-frequency channels. A terminal, marked LF RECEIVER, is provided on the front panel for connection to the antenna circuit of a receiver, such as the R-23/ARC-5. When the LF REC-NORMAL switch is in the LF REC position, the LF RECEIVER terminal is coupled to the ANTENNA terminal, and the low-frequency receiver can be operated from the same antenna.

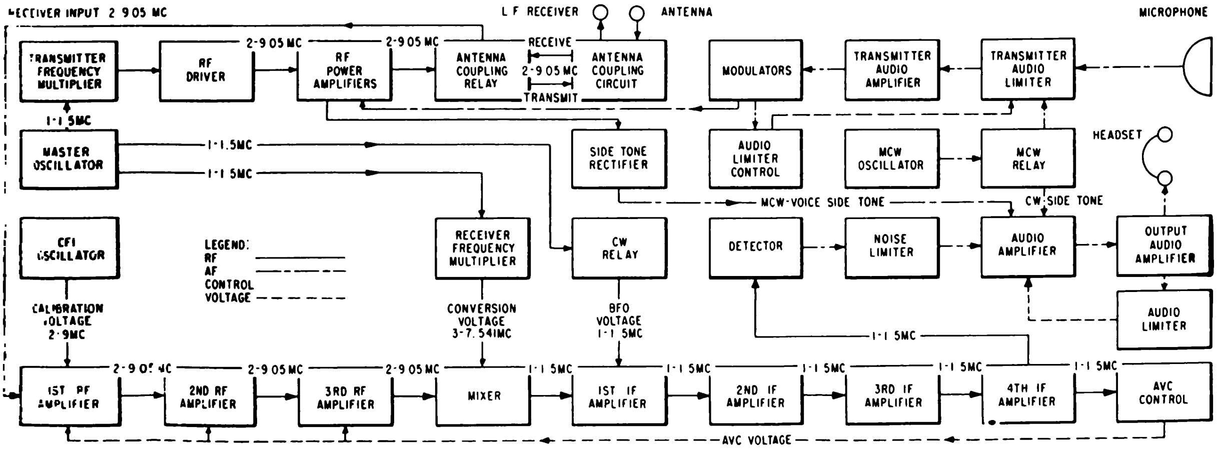


Figure 9-12.—Block diagram of ARC-2 and ARC-2A.

As shown in the block diagram, (fig. 9-12), some circuits are common to both the receiver and transmitter. These are the low-and high-voltage power supplies, MCW oscillator and relay, antenna coupling relay and circuits, and the master oscillator.

AN/ARC-38 TRANSCEIVER

Radio receiver-transmitter AN/ARC-38 is another transceiver that employs autotuning. Frequency coverage of the ARC-38 is 2 to 25 mc., which places it in the high-frequency range. Provision is made for 20 preset channels. In addition, any frequency within the transceiver's range may be set manually by control box C-1398. (See fig. 9-17.)

The transceiver has an output of 90-100 watts, and may be used at full power up to 50,000 feet. Its output impedance is 52 ohms and the output is normally connected to antenna coupler CU-351 (not discussed in this training course). This coupler automatically matches the transmitter output to an aircraft antenna that may be 45 to 100 feet in length.

Two types of transmission and reception are possible with the ARC-38: CW and amplitude-modulated radiotelephony (voice).

Figure 9-13 shows the main components of the system. RT-311/ARC-38 is the main unit of the system, and it is controlled by separately housed control units. C-1398/ARC-38 is used as a master control unit, from which 35,000 channels may be selected. A memory drum is included within this unit which enables the presetting of any 20 channels within the 35,000-channel frequency spectrum. With the memory drum preset, any of the 20 preset channels may be selected locally with the use of control C-1398, or remotely with the use of control C-1399.

The 52-ohm transmission line from the transceiver is automatically matched to the antenna coupler CU-351/AR. (See fig. 9-14.) Refer to the HSI (NavAer 16-30ARC/38-502) for a discussion of this unit.

The theory of operation of the ARC-38 can be broken down into three general descriptive sections: the transmitter, the receiver, and the control sections. The following discussion will, in general, follow this outline. However, since many of the ARC-38 functions are interdependent, a certain amount of overlap is unavoidable.

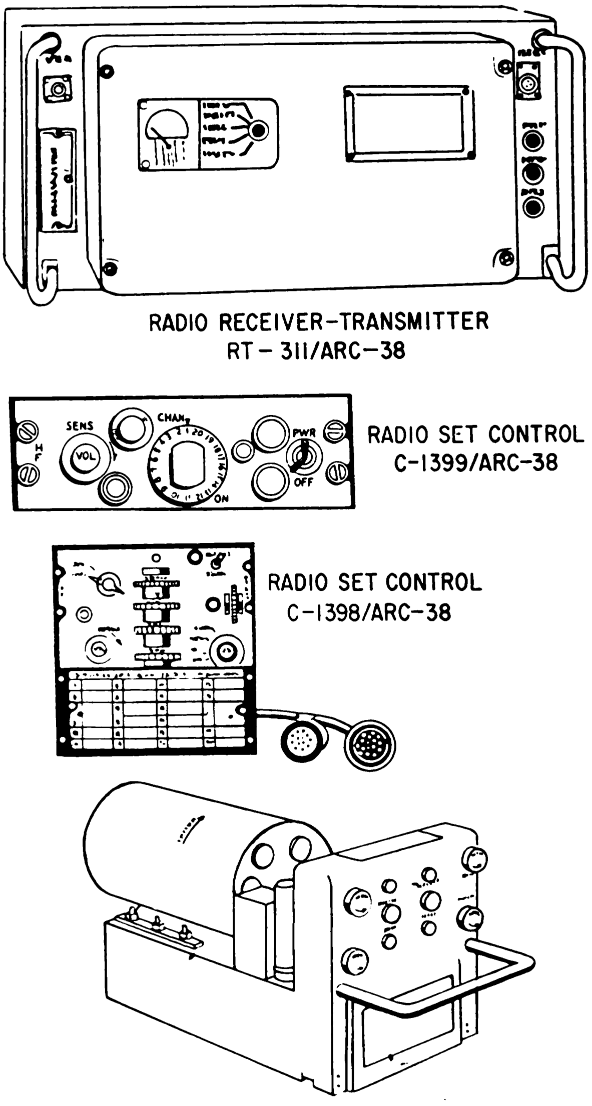


Figure 9-13.—Radio set AN/ARC-38.

Transmitter Section

A block diagram of the transmitter section of the transceiver is shown in figure 9-15. Fundamental frequencies are generated in the stabilized master oscillator (SMO) group. (The upper limit of the SMO output frequency actually varies somewhat according to the particular band; refer to note 2 of figure 9-15.) Circuitry contained within control C-1398 supplies the necessary information to the SMO group to alter its frequency the correct amount during the channeling cycle. The SMO group has three distinct outputs; one which feeds a

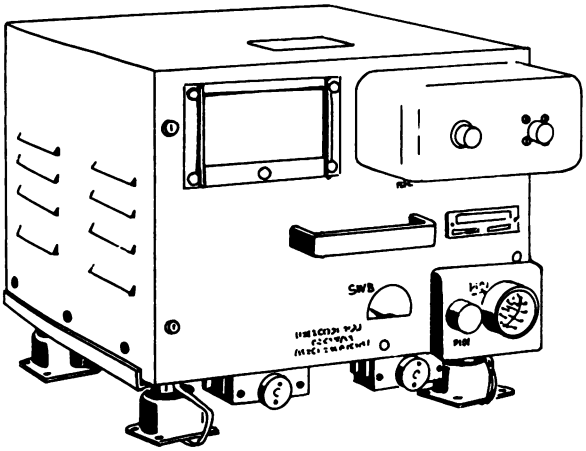


Figure 9-14.—Antenna coupler CU-351/AR.

discriminator and servo system for purposes of tuning all the low-level tuned circuits; one which supplies the basic frequencies to multiplier circuits for the purpose of establishing an injection voltage to the second transmitter mixer; and one which supplies the basic transmitter input to the first transmitter mixer, *V*1004.

The fundamental frequencies from the SMO that are supplied to *V*1004 are mixed with an injection frequency of 250 kilocycles, supplied by *V*1201 and associated circuitry. The sum frequency is selected by tuned circuits *Z*1002 and *Z*1003 and amplified by variable IF amplifier *V*1002. Tuned circuits *Z*1004 and *Z*1005 provide further selectivity of the variable IF signal. The signal is then applied to the second transmitter mixer, *V*1003, to be mixed with the multiplier output frequencies.

A muting circuit is included with *V*1003 to prevent spurious transmissions during the channeling cycle of the low-level circuits. The two frequencies present at *V*1003 are mixed and the sum frequency is selected by a tuned circuit—*Z*1014, *Z*1015, *Z*1016, or *Z*1017—depending upon the band of operation. All band-switching is accomplished by autopositioner motor *B*103 in conjunction with the band-change autopositioner and control *C*-1398. The RF signal is then amplified by the second RF amplifier, *V*1009, and applied through one of the four tuned circuits, *Z*1018 through *Z*1021, depending upon the band selected.

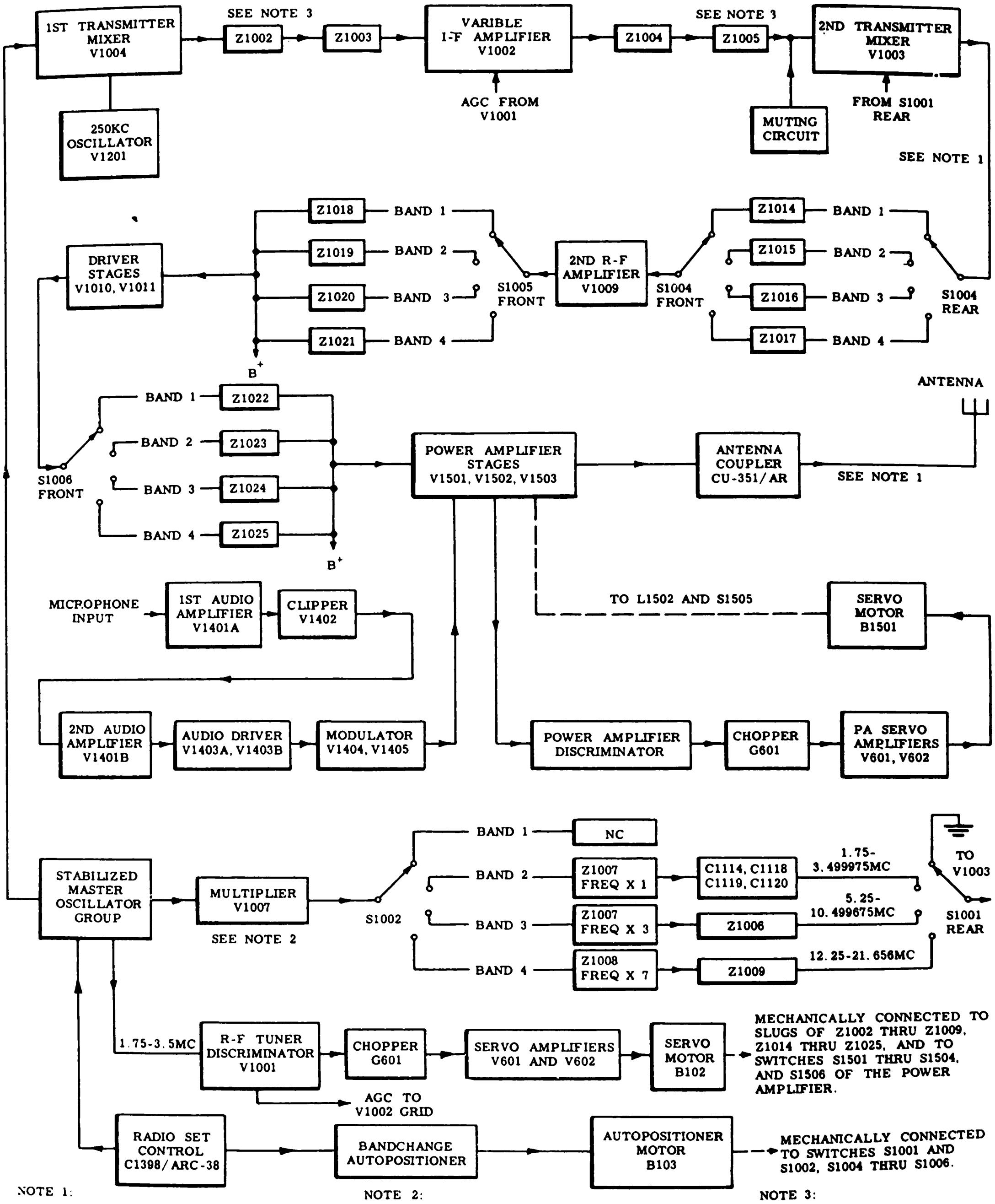
Two driver tubes, *V*1010 and *V*1011, are connected in parallel for final amplification before the RF signal is applied to the power amplifier stages. Selectivity for the driver stages is accomplished by tuned circuits *Z*1022 through *Z*1025. The signal is applied to the power amplifier, consisting of three tubes, *V*1501, *V*1502, and *V*1503, connected in parallel. At this point, an audio signal from the modulator is used to vary the plate and screen voltage of the power amplifier tubes to accomplish amplitude modulation of the carrier. The power amplifier subassembly contains its own servo system, which adjusts the main tuning inductor, *L*1502, to the correct frequency, as established in the low-level circuits. Output of the power amplifier is applied to the antenna through antenna coupler CU-351/AR.

Receiver Section

Figure 9-16 is a block diagram of the receiver section of the transceiver. Both sections of switch *S*1003, as well as all other bandswitches, are operated by autopositioner motor *B*103, which receives its information from control C-1398, in conjunction with the band-change autopositioner. The slugs of all tuned circuits within the receiver section of the transcevier are driven by servomotor *B*102 whenever a new channel is selected. Servomotor *B*102 receives its information from the stabilized master oscillator group and a discriminator and servo amplifier system, consisting of *V*1001, *G*601, *V*601, and *V*602.

An RF signal, within the frequency range of 2 to 25 mc., is induced into the antenna and applied through contacts of switch *S*1003 rear, through 1 of 4 tuned circuits, and through contacts of switch *S*1003 front to the control grid of *V*1008.

The RF signal from the antenna is amplified by *V*1008 and applied through a similar tuned circuit and switching arrangement, consisting of *Z*1014 through *Z*1017 and switches *S*1004 front and rear. The signal is amplified by the second RF amplifier, *V*1009, applied through *Z*1018, *Z*1019, *Z*1020, or *Z*1021, depending upon the position of *S*1005 front and rear, and applied to the control grid of the first receiver mixer, *V*1005. An injection signal, which originates in the stabilized master oscillator group, is applied through the multiplier stage (*V*1007), through multiplier tuned circuits (*Z*1006 through *Z*1009), to grid 3 of *V*1005. At this stage the two signals (one from the antenna and RF amplifiers, and the other from the SMO group and multipliers) are mixed in the electron stream of *V*1005, producing an output signal within the range of 2 to 3.75 mc. (The upper limit of the variable IF frequency actually


1ST TRANSMITTER MIXER V1004
SEE NOTE 3
Z1002
Z1003
VARIBLE I-F AMPLIFIER V1002
AGC FROM V1001
SEE NOTE 3
Z1004
Z1005
2ND TRANSMITTER MIXER V1003
MUTING CIRCUIT
FROM S1001 REAR
SEE NOTE 1
250KC OSCILLATOR V1201
Z1018
BAND 1
Z1019
BAND 2
Z1020
BAND 3
Z1021
BAND 4
DRIVER STAGES V1010, V1011
S1005 FRONT
2ND R-F AMPLIFIER V1009
S1004 FRONT
Z1014
BAND 1
Z1015
BAND 2
Z1016
BAND 3
Z1017
BAND 4
S1004 REAR
B+
BAND 1
Z1022
BAND 2
Z1023
BAND 3
Z1024
BAND 4
Z1025
S1006 FRONT
B+
POWER AMPLIFIER STAGES V1501, V1502, V1503
ANTENNA COUPLER CU-351/AR
ANTENNA
SEE NOTE 1
MICROPHONE INPUT
1ST AUDIO AMPLIFIER V1401A
CLIPPER V1402
TO L1502 AND S1505
SERVO MOTOR B1501
2ND AUDIO AMPLIFIER V1401B
AUDIO DRIVER V1403A, V1403B
MODULATOR V1404, V1405
POWER AMPLIFIER DISCRIMINATOR
CHOPPER G601
PA SERVO AMPLIFIERS V601, V602
BAND 1
NC
STABILIZED MASTER OSCILLATOR GROUP
MULTIPLIER V1007
SEE NOTE 2
S1002
BAND 2
Z1007 FREQ X 1
C1114, C1118 C1119, C1120
1.75-3.499975MC
BAND 3
Z1007 FREQ X 3
Z1006
5.25-10.499675MC
BAND 4
Z1008 FREQ X 7
Z1009
12.25-21.656MC
TO V1003
S1001 REAR
1.75-3.5MC
R-F TUNER DISCRIMINATOR V1001
CHOPPER G601
SERVO AMPLIFIERS V601 AND V602
SERVO MOTOR B102
MECHANICALLY CONNECTED TO SLUGS OF Z1002 THRU Z1009, Z1014 THRU Z1025, AND TO SWITCHES S1501 THRU S1504, AND S1506 OF THE POWER AMPLIFIER.
AGC TO V1002 GRID
RADIO SET CONTROL C1398/ARC-38
BANDCHANGE AUTOPOSITIONER
AUTOPOSITIONER MOTOR B103
MECHANICALLY CONNECTED TO SWITCHES S1001 AND S1002, S1004 THRU S1006.

NOTE 1:

OUTPUT FREQUENCIES:
BAND 1; 2-3.7495MC
BAND 2; 3.75-7.2495MC
BAND 3; 7.25-14.2495MC
BAND 4: 14.25-25MC

NOTE 2:

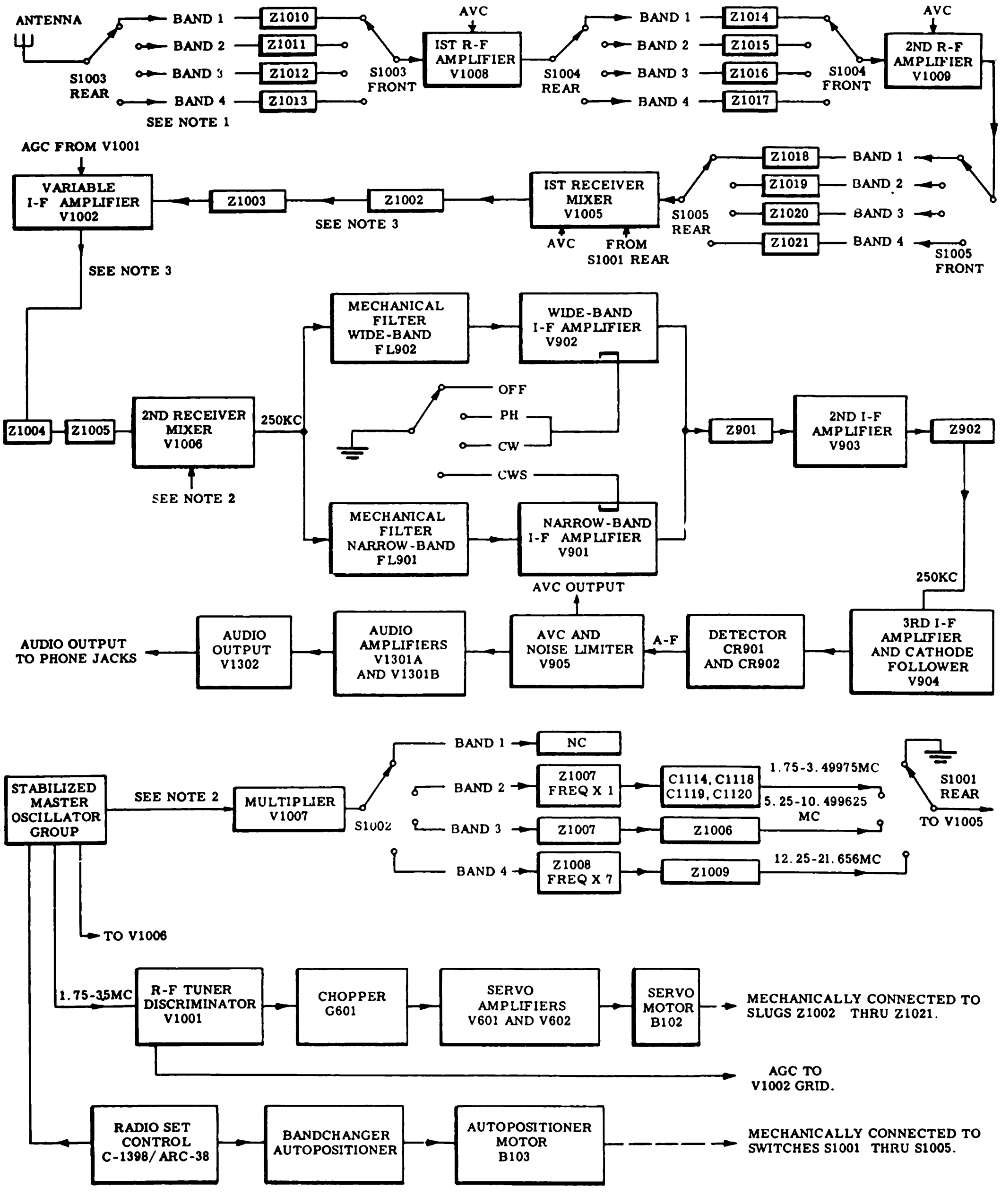
SMO OUTPUT FREQUENCIES:
BAND 1; 1.75-3.4995MC
BAND 2; 1.75-3.49975MC
BAND 3; 1.75-3.499875MC
BAND 4: 1.75-3.09375MC

NOTE 3:

VARIABLE I-F FREQUENCIES:
BAND 1; 2-3.7495MC
BAND 2; 2-3.74975MC
BAND 3; 2-3.74985MC
BAND 4; 2-3.34375MC

Figure 9-15.—Radio set AN/ARC-38, transmitter section, block diagram.

varies somewhat according to the particular band. Refer to note 3 of figure 9-16.) The 2- to 3.75-mc. signal is applied through tuned circuits *Z*1002 and *Z*1003 to the control grid of the variable IF amplifier *V*1002. The variable IF signal is amplified by *V*1002 and applied through tuned circuits *Z*1004 and *Z*1005 to the control grid of the second receiver mixer, *V*1006. An injection voltage from the SMO group, within the frequency range of 1.75 to



NOTE 1:
INPUT FREQUENCIES:
BAND 1; 2-3.7495MC
BAND 2; 3.75-7.2495MC
BAND 3; 7.25-14.2495MC
BAND 4; 14.25-25MC

NOTE 2:
SMO OUTPUT FREQUENCIES:
BAND 1; 1.75-3.4995MC
BAND 2; 1.75-3.4995MC
BAND 3; 1.75-3.499875MC
BAND 4; 1.75-3.09375MC

NOTE 3:
VARIABLE I-F FREQUENCIES:
BAND 1; 2-3.7495MC
BAND 2; 2-3.74975MC
BAND 3; 2-3.74985MC
BAND 4; 2-3.34375MC

Figure 9-16.—Radio set AN/ARC-38, receiver section, block diagram.

3.5 mc., is applied to grid 3 of *V*1006. The two signals (one of 2 to 3.75 mc. from the main signal line and the other of 1.75 to 3.5 mc. from the SMO group) are heterodyned in the electron stream of *V*1006 and an IF of 250 kc. is produced. This signal is then applied through the wide- and narrow-band mechanical filters, *FL*902 and *FL*901 respectively.

The cathodes of IF amplifiers *V*901 and *V*902 are connected to the function selector switch of control C-1398. When the function selector is operated to the PH or CW positions, the cathode of *V*902 is grounded, and in the CWS position the cathode of *V*901 is grounded. Thus, the mechanical filter in use depends upon the position of the function selector switch of control box C-1398. Each mechanical filter has a center frequency of 250 kilocycles. This frequency is passed on, while all others are filtered out. (Mechanical filters are explained in chapter 10 in connection with single sideband (SSB).) The 250-kilocycle signal is amplified by either *V*901 or *V*902 and applied through tuned circuit *Z*901 to the control grid of the second IF amplifier, *V*903. The signal is amplified by *V*903 and applied through *Z*902 to *V*904.

Tube *V*904 is a dual-triode stage, with one-half acting as a conventional IF amplifier and the other half acting as a cathode follower. The cathode follower performs the function of isolating the IF amplifiers from the detector circuit. The audio portion of the signal is recovered in the detector, consisting of crystal rectifiers *CR*901, *CR*902, and associated circuitry. The audio signal is applied to the avc and noise limiter stage, *V*905, which performs the dual functions of clipping strong noise pulses and delaying the application of avc voltage until a fixed bias of 30 volts d.c. has been overcome. The audio signal is amplified by *V*1301A and *V*1301B and applied to the control grid of the audio output stage, *V*1302. Output from *V*1302 is connected to the phone jacks.

Control Section

Control box C-1398 (fig. 9-17) is the main control unit for the ARC-38, and it will be located near the radio operator. This control box is used in setting frequencies, either manually or on the twenty available channels for automatic operation. It can select about 35,000 frequencies between 2 and 25 mc. It will also be used to select the type of emission desirable, CW or voice, and can transfer control to the remote control box C-1399. (See fig. 9-18.)

By lifting a hinged door located on the front panel of control C-1398, the following are accessible: a memory drum for presetting 20 channels, a tool for operating the preset functions of the memory drum, and a code book giving information necessary to set up the preset drum and manual frequency selection switches. A thumb wheel labeled CHAN for presetting channel selection and four switches operated by thumb wheels for manual frequency selection are provided. A three-position rotary switch labeled MAN-LOCAL-REMOTE is provided for selection of the location from which frequencies may be selected. At the MAN position, frequencies are selected by adjusting the four thumb-wheel switches on this control. At LOCAL position, frequencies are selected by adjusting the thumb-wheel switch labeled CHAN. In the REMOTE position, frequencies are selected at C-1399 by adjusting the 20-position rotary switch labeled CHAN on that control.

Control C-1398 is provided with the necessary gain controls marked VOL and SENS. A four-position rotary function switch labeled OFF PH CW CWS is used to select type of emission, receiver selectivity, and to control power to the equipment. A control labeled BFO is used for remote control of the beat-frequency oscillator. Also located on the front panel is a single-pole, double-throw switch labeled CW XMSN - CW RECPT which disables the dynamotor in CW RECPT position to permit monitoring the received signal without operating the dynamotor.

Control C-1399 (fig. 9-18) functions only when control C-1398 is in the REMOTE position. PH operation is selected automatically when C-1398 is switched to the REMOTE position.

Setting Frequencies on Memory Drum

A pecularity of control box C-1398 is that in order to set a frequency on the memory drum it is necessary to select a channel which differs from the desired channel by 9. That is, if channel 1 is to be set, channel 10 must be selected on the CHAN selector. This is shown in figure 9-17. Also note that a 1 appears in the small window by the memory drum labeled SET CHAN.

An explanation as to why the memory drum is set in this manner is beyond the intended scope of this training course. However, a detailed explanation is contained in the HOI (NavAer 16-30ARC38-501).

The operating manual for control box C-1398 is located in a slot under the hinged door on the control unit. The manual contains a list of all available frequencies from 2.0 to 25.0 mc., memory drum pin settings, and manual switch settings for each frequency listed.

The following is a sample frequency from the manual:

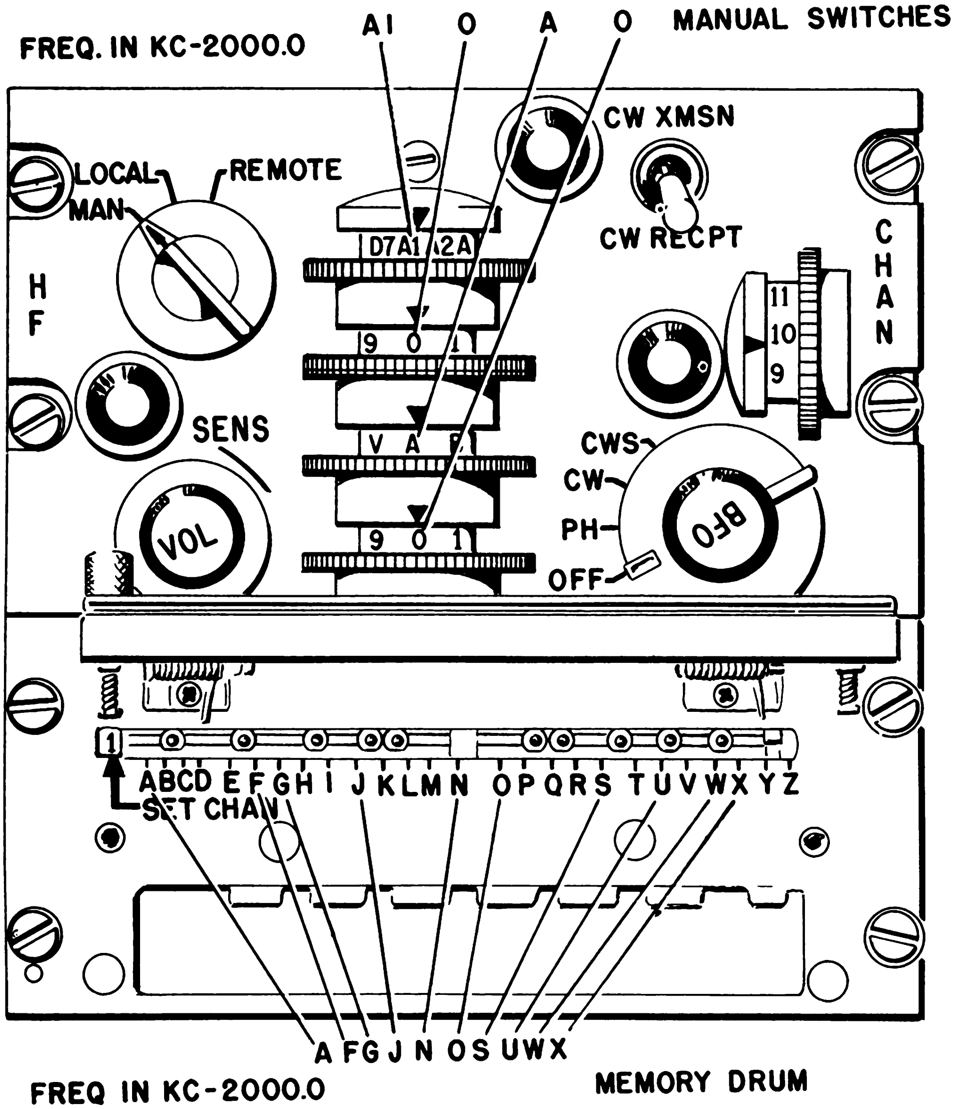


Figure 9-17.—Control box C-1398, sample frequency setup.

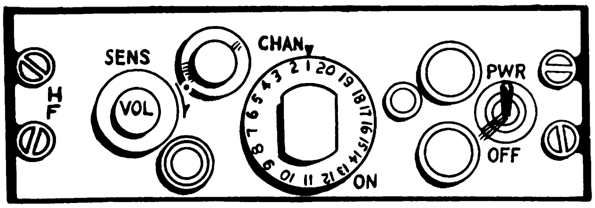


Figure 9-18.—Control box C-1399.

FREQ.IN KC.	MANUAL SWITCH	MEMORY DRUM
2,000.0	A1 0 A 0	A FG JN OS UWX

In order to set 2,000.0 kc. (2 mc.) on a channel of the memory drum, the operator will select the proper channel indicated in the operating manual to expose the desired channel pins of the memory drum. In figure 9-17 it is desired to set 2,000.0 kc. on channel one, so the CHAN selector is set at channel 10 to expose the channel one pins. The pins are then adjusted to the letters indicated opposite 2,000.0 kc. in the operating manual under MEMORY DRUM, or A FG JN OS UWX. (The pins shown in figure 9-17 are not set for this frequency.) Once set, channel one will provide transmission and reception on 2,000.0 kc. everytime channel one is selected by the CHAN selector.

Setting Frequencies Manually

Should the operator wish to operate on 2,000.0 kc. without changing any of the 20 preset channels, he will first set the MAN LOCAL REMOTE switch to MAN. The next step is to dial in the four settings listed under MANUAL SWITCH, A1 0 A 0 (fig. 9-17). The transceiver is then set up to operate on 2,000.0 kc. as long as the MAN position is selected.

When the MAN LOCAL REMOTE switch is set in the REMOTE position, control is switched to the pilot's control box C-1399. The pilot may then select any of the 20 preset channels for operation.

Ultrahigh-Frequency Radio Equipment

AN/ARC-27 RADIO SET

Radio set AN/ARC-27 is an example of ultrahigh-frequency communications equipment designed for aircraft installation. The set is a transceiver, a combination of transmitting and receiving equipment contained in a single housing with many of the circuits functioning in both types of operation.

In construction and use, the AN/ARC-27 exhibits the advantages gained by employing the ultrahigh-frequency (UHF) region of the spectrum for aircraft communication. Many more operating channels are available than can be found in the comparatively crowded lower frequency bands. The static interference which is very troublesome in low-frequency radio reception is negligible in the ultrahigh region. Antennas resonant to these frequencies are comparatively small in size and hence are well adapted for aircraft use. The components of the equipment are usually small and light in comparison with low-frequency applications.

A disadvantage associated with operation at frequencies employed by this set lies in the restriction of the range of communication to line-of-sight limits. Ultrahigh-frequency waves are not effectively returned to earth by the ionosphere. Hence, the operating range is limited by the curvature of the earth and confined to areas enclosed by the horizon.

In discussion of this equipment, the present account is concerned only with the major functions of the set. Detailed schematic drawings and exact descriptions of all the various elements cannot be given here. The reader is referred to the *Handbook of Service Instructions* for information pertaining to the circuit details and maintenance procedures.

Purpose of the Equipment

Radio set AN/ARC-27 is a transmitter-receiver used for amplitude-modulation, radiotelephone communications between aircraft, between aircraft and shore installations, and between aircraft and ships. It also has provision for working in conjunction with radio compass AN/ARA-25. In operation the set may be considered as consisting of three major components: the main channel receiver, the guard channel receiver, and the transmitter. Many circuits are common to the receiving and transmitting functions.

The set operates in the range of frequencies from 225 to 399.9 megacycles. Within this range, 1,750 channels are provided at 0.1 mc. intervals. Tuning and channel selection are accomplished automatically by means of an autotune system. Using a remote control unit, the pilot can select any one of 18 preset operating channels. With the use of other type control boxes, he is able to select any one of 22 preset operating channels and to set the frequency of his choice on the channel of his choice. In addition, provision is made for reception and transmission on a guard channel.

The transmitter normally produces voice-modulated signals, but it can also be modulated by a 1,020-cycle tone for emergency use and for direction finding purposes.

Electrical Characteristics

The set is operated from a 27.5-volt d-c power source. The current required at 27.5 volts is as follows:

Operating condition	Amperes required
Reception	16.5
Transmission	19.1
Channel switching.	25.5

The output power of the transmitter is 9 watts minimum to 30 watts maximum. The main channel receiver develops 50 milliwatts of audio power in a 300-ohm resistive load when the RF signal input is 5 microvolts. The maximum output power developed by either the main channel or the guard channel receiver is 2 watts.

Description of Major Units

The major units of the AN/ARC-27 equipment include a receiver-transmitter, RT-178/ARC-27, the operator's control unit, C-626/ARC-27, and the pilot's unit, C-628/ARC-27.

The receiver-transmitter is shown in figure 9-19. The unit weighs 70.5 pounds and is enclosed in a pressurized, aluminum case. Pressurization of the enclosure with dry air assists in preventing voltage breakdown when the unit is operated at high altitudes. The case also performs the functions of protective cover, electrical shield, and heat exchanger.

The entire receiver-transmitter is composed of 11 groups of plug-in subassembly units which are interchangeable from one set of equipment to another. The front panel of the unit contains the sensitivity controls of the main and guard channel receivers, the squelch circuit controls, a meter jack, a meter switch, and head set and microphone jacks. The receiver-transmitter is mounted on a plate which contains four shock absorbers. Control and power cables and antenna connections are located on the front panel.

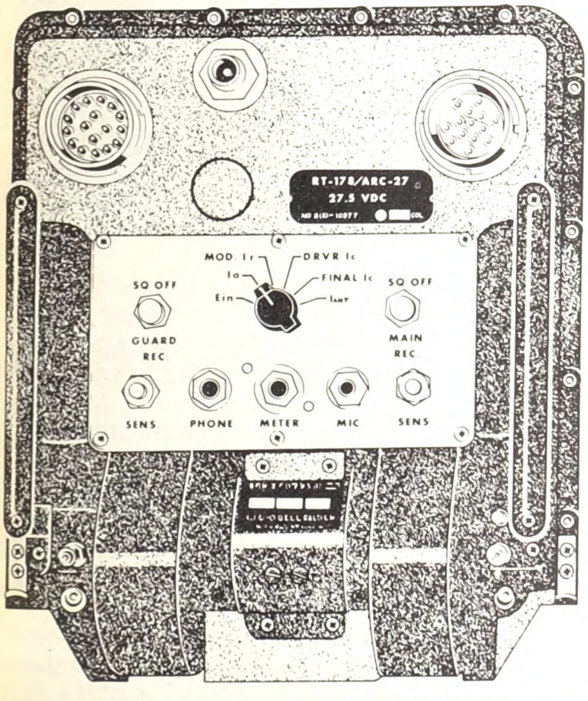


Figure 9-19.—Receiver-transmitter RT-178/ARC-27, front panel.

The operator's control unit, C-626/ARC-27, is shown in figure 9-20.

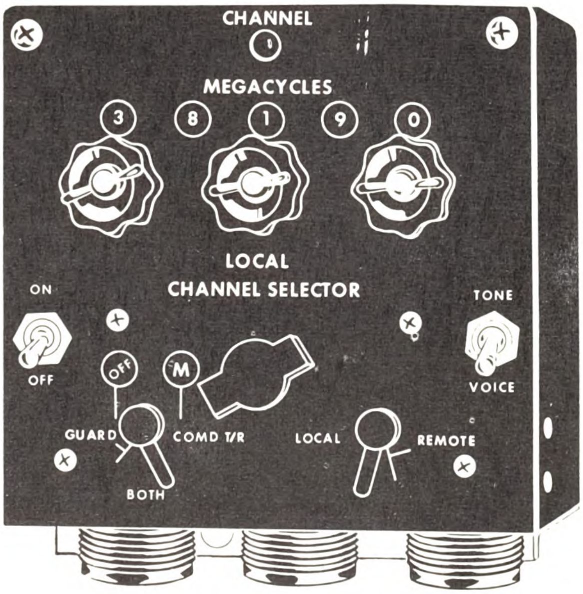


Figure 9-20.—Control C-626/ARC-27.

Three frequency selector knobs are included in the operator's control unit. Each of these knobs sets a selector switch associated with an autopositioner unit in the receiver-transmitter unit. The autopositioners tune the equipment to the frequency indicated on the control unit. Preset channels may be selected either by the local channel selector on the C-626 or from the pilot's control unit C-628.

The method of setting the operating frequency on each of the 18 channels and the guard channel by use of the operator's control unit is illustrated by the following procedure.

The Local-Remote switch is set to the LOCAL position, and the equipment is turned on. The COMD T/R position of the function switch is selected. The Local Channel Selector switch is set to the number of the channel to be adjusted, for example, channel 1. The three wing nuts are loosened and the frequency control knobs are rotated until the numerals in the windows indicate the frequency desired for channel 1. The wing nuts are then tightened and the Local Channel Selector switch shifted to any position other than that of channel 1. Upon returning the Local Channel Selector switch to position 1, the frequency selected should again appear in the numerals within the windows. The same procedure is repeated for the other 17 channels. To set the guard channel frequency, the function switch is placed in the GUARD position and the above procedure is repeated. All physical adjustments of the tuning circuits are made by the autotune mechanism and the autopositioner units in the receiver-transmitter.

The pilot's control unit, C-628/ARC-27, contains an audio volume control knob, a channel selector dial, and a function selector switch.

Theory of Operation

The operation of radio set AN/ARC-27 in reception and transmission is based on the functions of four principal groups of circuits. These are the main channel receiver, the guard channel receiver, the spectrum system, and the transmitter. In addition, tuning and control are accomplished by means of the autotune and autopositioner units.

The main channel receiver is a triple-conversion superheterodyne containing three crystal oscillators which are provided with automatic crystal selection.

The guard channel receiver is a fixed frequency superheterodyne employing double conversion. The two receivers have a common audio output amplifier.

Many of the circuits in the set are arranged so that signals pass through them in one direction during reception and in the opposite direction during transmission. Excitation signals for the transmitter are produced through a process of frequency conversion, in which the output of a tunable IF amplifier stage is mixed with the output of a crystal-controlled spectrum generating system. Injection signals for the first mixer of the main receiver are also produced by the crystal spectrum circuits.

The spectrum system contains a crystal oscillator, buffer stage, harmonic generator stages, frequency mixers, and selective amplifiers; and by combining signals from the harmonic generator stages, it produces the frequency range from 200 to 370 mc. in 10 mc. steps.

Main Channel Receiver

The block diagram of the main receiver is shown in figure 9-21.

In construction, the main receiver is composed of a number of subassemblies, some of which are also used in transmitter operation.

The RF amplifier section is used only in reception. It contains two stages of grounded-grid amplifiers. The grids are grounded to RF bypass capacitors which are specially constructed of flat plates and mica spacers. The capacitors are built into the chassis adjacent to the tube sockets. The input signals are applied to the cathode circuits of the RF amplifiers. Selectivity is provided by three tuned circuits with the variable elements ganged and controlled by a shaft operated by the automatic tuning system. In both tubes, avc voltage is applied to the grids to control the gain with strong input signals.

The output of the second RF amplifier is coupled to the cathode of a mixer tube where the incoming signal is converted in frequency by mixing it with the injection signal supplied by the spectrum amplifier. Coupling of the local injection signal to the mixer cathode is made by means of the capacitance between two conductors of a short length of specially constructed cable.

The difference frequency obtained by mixing is coupled from the mixer to the input of the 20-30 mc. intermediate amplifier subassembly. The coupling is made through connectors which consist of flat springs and button contacts.

The 20-30 mc. intermediate amplifier subassembly contains two stages of IF tubes followed by a mixer. These stages have variable tuning provided by adjustable IF transformers. Tuning of the transformers is accomplished by powdered-iron slugs which are controlled in position by the automatic tuning system. Following the second IF amplifier is a pentode mixer. In this tube a second conversion of the incoming signal is made by combining the 20-30 mc. output with a local injection signal produced by a crystal oscillator. Ten crystals are available in the oscillator circuit. A switch ganged with the IF tuning adjustments is employed to select the appropriate crystal for a given IF signal. The range of frequencies produced by the crystal oscillator extends from 25.7 to 34.7 mc., and combination of these values with the IF signals give a new range of IF signals from 4.8 to 5.7 mc.

The subassembly containing the 20-30 mc. IF amplifiers used in reception also contains three pentode amplifiers which operate only during transmission. The same coupling transformers are used both for receiving and

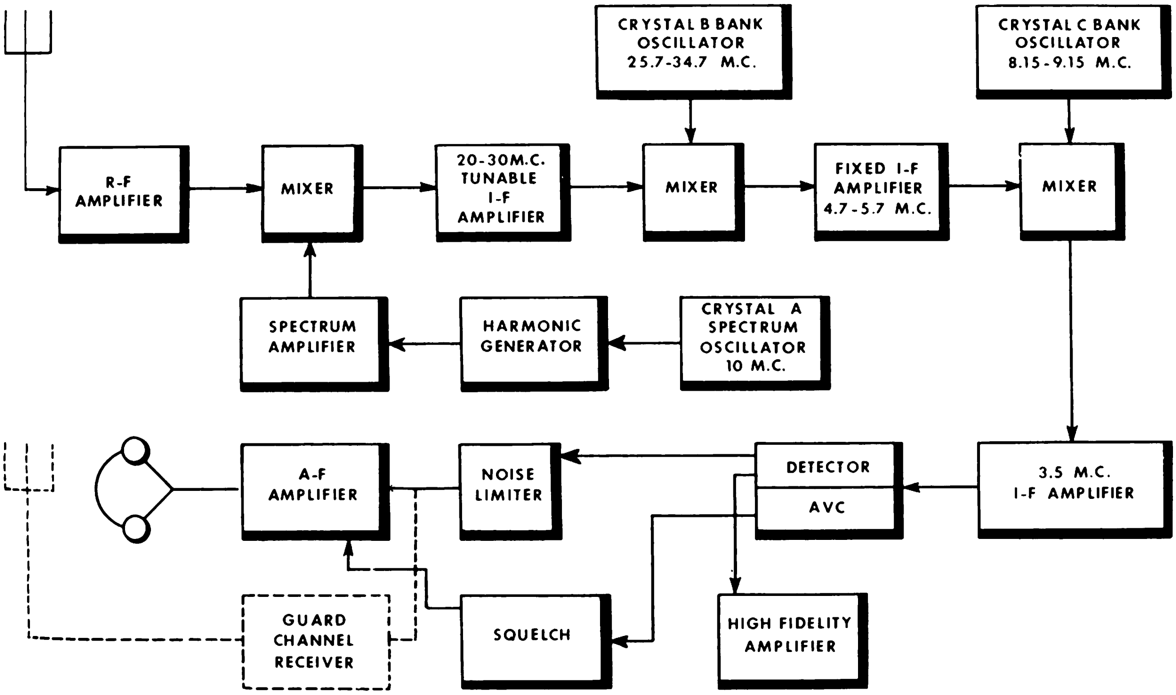

CRYSTAL B BANK OSCILLATOR 25.7-34.7 M.C.
CRYSTAL C BANK OSCILLATOR 8.15-9.15 M.C.
R-F AMPLIFIER
MIXER
20-30M.C. TUNABLE I-F AMPLIFIER
MIXER
FIXED I-F AMPLIFIER 4.7-5.7 M.C.
MIXER
SPECTRUM AMPLIFIER
HARMONIC GENERATOR
CRYSTAL A SPECTRUM OSCILLATOR 10 M.C.
A-F AMPLIFIER
NOISE LIMITER
DETECTOR
AVC
3.5 M.C. I-F AMPLIFIER
GUARD CHANNEL RECEIVER
SQUELCH
HIGH FIDELITY AMPLIFIER

Figure 9-21.—Main receiver block diagram, AN/ARC-27.

transmission. The coil which serves as a transformer primary during reception serves as a transformer secondary during transmission. In this arrangement, the transmitter signal travels through the subassembly in the direction opposite to the path of the received signal. These transformers are called "bilateral tank circuits."

After the second conversion, received signels are applied to the 4.8-5.7 mc. intermediate-frequency amplifier subassembly. This section contains two amplifiers followed by another mixer, and is similar in layout to the previous bilateral IF section. It contains one set of tubes for receiver operation and another for transmitter operation. The 4.8-5.7 mc. amplifiers do not contain variable tuning elements.

The output signal from the second IF section is applied to the third mixer where it is combined with the output of a crystal oscillator controlled by one of the crystals in the C bank. The difference frequency signal resulting from this action is applied to the input of the first of three IF amplifier circuits which are tuned to 3.45 mc.

Audio Stages

The amplified IF output at 3.45 mc. is applied to a diode detector and to an avc rectifier. The audio signal derived from the detector is applied to the first audio amplifier through a series noise limiter diode which removes any high amplitude noise impulses. The noise limiter circuit contains an additional shunt diode limiter which effectively short-circuits the secondary of the IF transformer for the duration of the noise pulse. This prevents the noise voltage from affecting the avc circuit with a resulting lowering of the gain of the IF and RF amplifiers.

After passing through the noise limiting circuit, the audio signals are coupled to the grid of the first audio amplifier tube. This tube is controlled by the action of a squelch circuit which disables the AF amplifier in the intervals of standby operation when there is no carrier applied to the receiver input. When no signals are being received, the avc circuit permits the squelch tube to draw high current through a resistor connected between the grid and cathode of the first audio amplifier tube. The resulting voltage drop biases the AF amplifier grid to cutoff so that any random noise voltage present in the input of the audio system is not amplified and passed on to the phones.

When a carrier is applied to the receiver, the action of the avc circuit causes a negative bias-supply voltage to be applied to the grid of the squelch tube. The squelch current is cut off, reducing the bias on the AF amplifier grid and allowing the amplifier to operate.

The audio output of the detector is amplified in three stages of AF amplification and is applied to the output phone jacks. The maximum output power that can be developed by the final audio amplifier is about two watts.

A portion of the audio output of the detector is applied to the input of a cathode follower stage which couples audio signals up to 20,000 cycles per second to a pin connection in the receiver-transmitter. This output is used to operate the AN/ARA-25 radio compass.

Guard Channel Receiver

The guard channel receiver is a dual-conversion superheterodyne. The principal stages are shown in the functional block diagram of figure 9-22.

One stage of RF amplification and three tuned circuits are provided. The tuned circuits insure sufficient selectivity to prevent image-frequency reception.

Injection voltage for the first mixer is supplied by a cathode-coupled crystal oscillator and a frequency multiplier system. The crystal frequency (which is 37.266 mc. when the guard frequency is 243 mc.) is multiplied six times to 223.6 mc. and coupled to the cathode of the mixer tube. The output circuit of the mixer is tuned to 19.4 mc. This value is the difference of the guard frequency and the frequency of the multiplied crystal output.

The output of the first mixer, a 19.4-mc. signal, is amplified in one stage of IF amplification and the mixer process is repeated to reduce the signal frequency to 3.45 mc. The second injection oscillator is also crystal-controlled, and operates at 15.95 mc. The 3.45-mc. value is produced by combining the IF signal and the second injection voltage in a second mixer. Two stages of 3.45-mc. amplification are used.

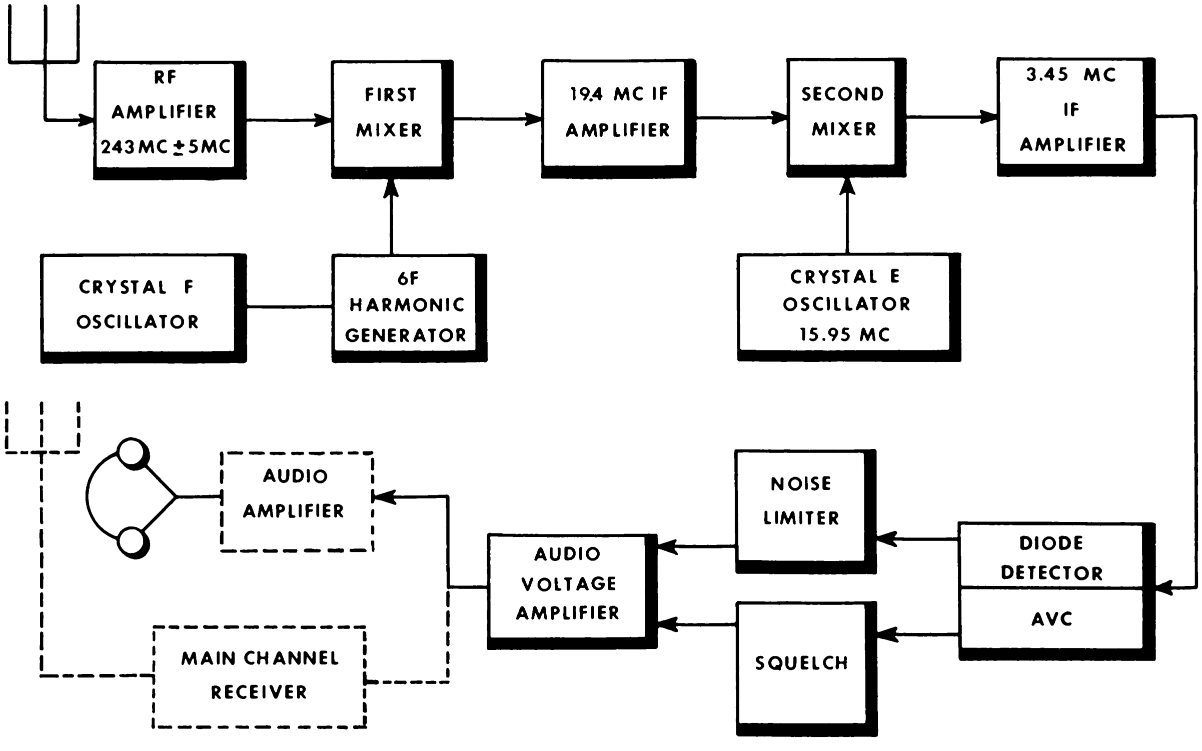


Figure 9-22.—Guard channel receiver block diagram.

As shown in the diagram, the output of the guard receiver is derived from the same stages which serve as final audio amplifiers in the main channel receiver. Otherwise the two receivers operate independently.

The guard receiver audio system includes a diode detector, a noise limiter, an avc rectifier and avc amplifier, a squelch tube, and an audio voltage amplifier. These circuits operate independently so that strong signals in the main channel receiver do not affect the avc and gain of the guard channel receiver.

Transmitter Operation

The transmitter section of the AN/ARC-27 equipment is shown in block diagram form in figure 9-23.

operation. The D oscillator generates a 3.45-megacycle signal voltage and couples it to a mixer tube to which the output of the C oscillator is coupled. The C oscillator generates signals in the frequency range from 8.25 to 9.15 mc. in ten steps of 0.1 mc. One of ten crystals is automatically selected by the tuning mechanism to give the correct value for the operating channel selected at the control unit.

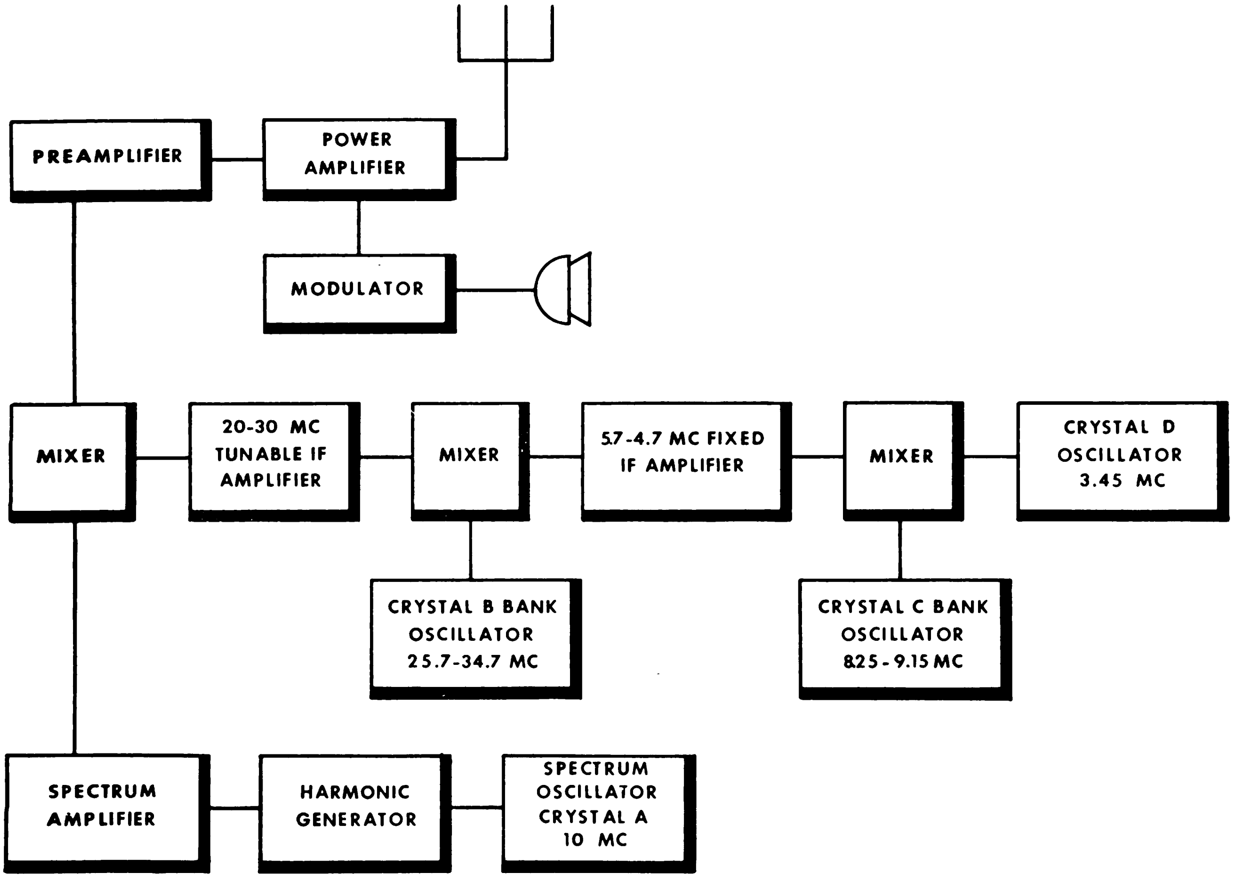

PREAMPLIFIER
POWER AMPLIFIER
MODULATOR
MIXER
20-30 MC TUNABLE IF AMPLIFIER
MIXER
5.7-4.7 MC FIXED IF AMPLIFIER
MIXER
CRYSTAL D OSCILLATOR 3.45 MC
CRYSTAL B BANK OSCILLATOR 25.7-34.7 MC
CRYSTAL C BANK OSCILLATOR 8.25-9.15 MC
SPECTRUM AMPLIFIER
HARMONIC GENERATOR
SPECTRUM OSCILLATOR CRYSTAL A 10 MC

Figure 9-23.—Block diagram of transmitter RT-178/ARC-27.

The transmitter generates and radiates signals in the 225 to 399.9 mc. range with a carrier power of about 9 watts minimum to 30 watts maximum. The carrier frequency is generated by mixing the output of the spectrum amplifier with the output of the 20-30 mc. IF amplifier subassembly.

The 20-30 mc. output signal is produced by mixing the voltages developed by the B, C, and D crystal oscillators in the arrangement shown in figure 9-23. The process begins in the D oscillator, a crystal-controlled Colpitts circuit, which is used only in transmitter

The process of mixing the D and C oscillator signal voltages results in a difference frequency contained in the 4.8 to 5.7 mc. range. The resultant is amplified in fixed tuned amplifiers and applied to a second mixer tube to which the signal from the B oscillator is coupled. The B oscillator circuit generates crystal-controlled signals contained in the 25.7 to 34.7 mc. range.

The second process of mixing gives a difference frequency within the 20-30 mc. band which is amplified in the tunable IF subassembly. The amplified output of the IF section is applied to the transmitter mixer tube and combined with the output of the spectrum amplifier. Addition of frequency values occurs in the mixer to give signals in the 225 to 399.9 mc. range. These signals are used for transmitter excitation and after amplification are applied to the input of the power amplifier.

The output of the transmitter mixer is applied to the preamplifier section which selects and amplifies the signal for application to the power amplifier tubes.

The preamplifier contains three tuning circuits which are ganged and tuned by the automatic tuning mechanism. The adjustments are controlled by the settings of the selector dials of the operator's control unit.

The power amplifier section contains three tubes: A 2C39A output amplifier driven by another 2C39A which is driven by a 2C43. These tubes are grounded-grid triodes in which the grids are grounded to RF bypass capacitors. The input signals in each stage are applied to the cathodes. Resistors are connected between the grids and cathodes to provide d-c return paths. The resistor in the final tube is a potentiometer which is geared to the tuning circuit, and it varies over the tuning range so as to lower the gain of the amplifier at the middle frequencies and to raise the gain at the extremes of the range. This action causes the output power to have a nearly constant value at all operating frequencies.

The amplified RF energy is coupled from the final tank circuit by means of a one-turn loop connected to a length of coaxial cable. The cable is attached to the antenna through the contacts of an antenna change relay. The same antenna is used both for receiving and for transmitting.

Audio power for modulating the transmitter carrier is developed by a twin-pentode modulator, an 829B, operated in push-pull. The modulator output is developed across an inductance coil in the plate lead connecting the plates of the RF final tubes to the power supply, and audio modulating voltages are applied to the plates of all three power amplifier tubes.

The modulator is driven by a phase inverter of the cathode follower type employing one section of a twin-triode.

The Channel Selector System

One of the principal requirements of aircarft communications systems is that the pilot and the operator be provided with the means for making rapid and accurate selection of the operating frequency. Tuning must be accomplished without the need for setting numerous switches and dials and without the use of bulky components. To meet these requirements, the AN/ARC-27, like the AN/ART-13, is provided with an automatic tuning system with which the various adjustments of tuning circuits and switches are made by motor-driven shafts and gear trains.

The system used in the AN/ARC-27 contains two basic types of mechanisms, the autotune units and the autopositioners. The physical adjustments are made by the autopositioners. The autotune units set the positions of rotary switches which control the operations of the autopositioners.

These units are controlled by the master control, C-626/ARC-27, and by the pilot's remote control box. The master control unit permits selection of any one of 1,733 usable frequencies (frequencies ending in 0.0 are avoided). Selection of one of these is made by setting three dials on the control panel. Operation of these dials causes the autopositioner motor to run, driving various gears and shafts which tune the receiver-transmitter to the frequency selected.

The Local Channel Selector switch of the master control unit controls the action of the autotune units. In accordance with one of the 20 positions of the selector switch, the autotuners set rotary switches which operate the autopositioner motor, causing it to tune the receiver-transmitter to one of 18 preset operating channels or to the guard channel. (The twentieth position permits manual selection of any one of the 1,733 usable frequencies.)

The autotune units are employed in the master control unit. Each autotune sets a control switch. The three switches determine the operating frequency, and changes can be made in steps of 10, 1.0, and 0.1 megacycles.

A single motor drives all the autotune units through a gear train and a system of slip clutches. The autotune basic elements consist of a cam drum, a stop ring drum, and a pawl stack. These are shown in figure 9-24.

Each drum contains 19 offset slots. Each slot on the cam drum corresponds to a channel. Each position in which the stop ring drum comes to rest corresponds to an operating frequency. The stop ring drum is locked in place when one of the pawls engages slots in both the cam drum and the stop ring drum.

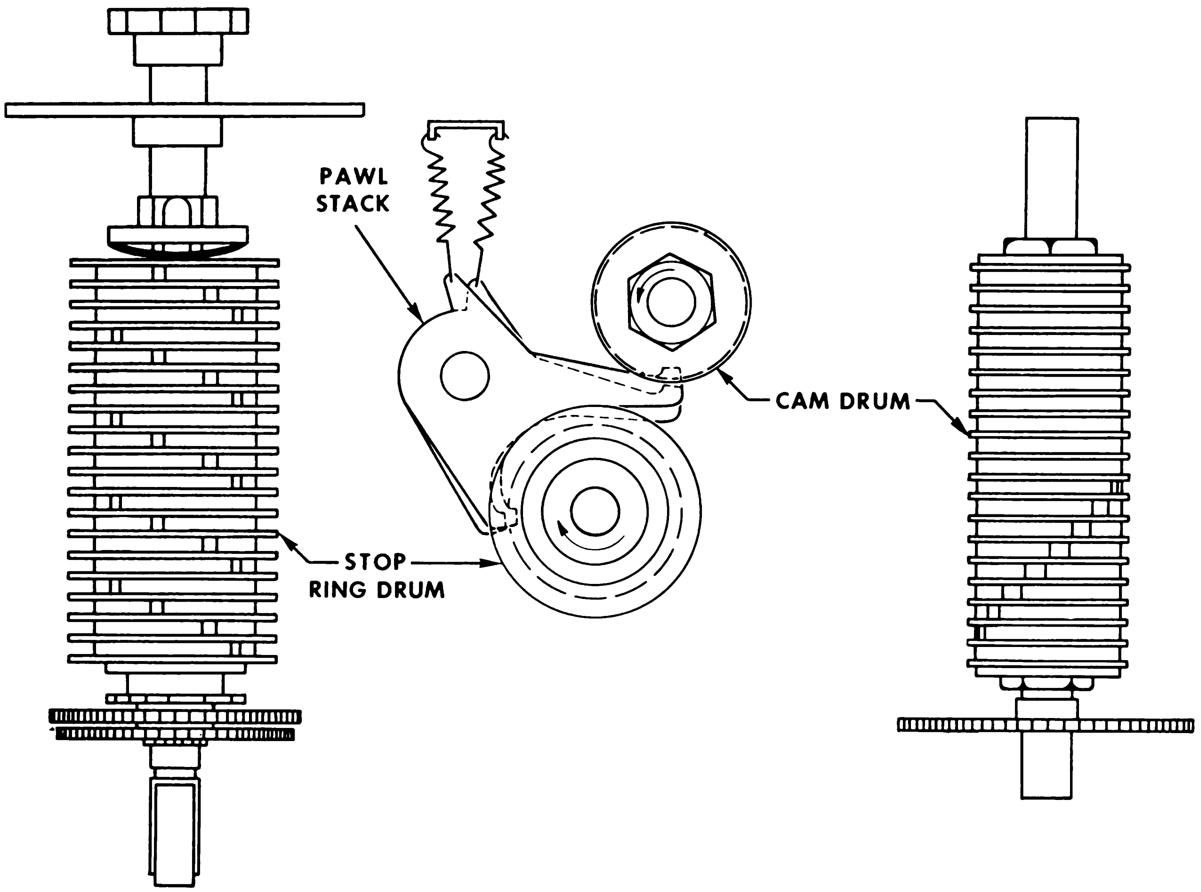


Figure 9-24.—Basic autotune elements, Radio Set Control C-626/ARC-27.

The general nature of the autotune action is as follows: When a channel is selected on the selector switch, a relay is energized, starting a motor which drives both drums through slip clutches. When the cam drum is positioned correctly for the channel selected, a rotary switch on the motor shaft reaches an open position. This results in relay action which stops the cam drum by dropping a pawl (not shown) into a notched stop wheel attached to the cam drum shaft. The clutch through which the cam drum is driven begins to slip, allowing the motor to continue rotating and to drive the stop ring drum. When the cam drum stops, one of the pawls, shown in figure 9-24, drops into one of the slots. Since the slots are offset, only one pawl can drop. It is then placed so that it can engage a slot in the stop ring drum, stopping its rotation. The stop ring positions set switches which govern the frequency to which the autopositioners tune the equipment.

The autopositioners are motor-driven units which adjust the tuning circuits and switches of the subassemblies in the receiver-transmitter. Autopositioner tuning action is controlled by the "open-circuit seeking" system, the basic principle of which may be explained by the diagram shown in figure 9-25.

The figure illustrates the principle of operation by showing a system of single-pole, double-throw switches in the circuit of the relay which controls the operation of the motor. The switches on the right, labeled "seeking switches" are operated by the rotation of the motor shaft. When the control switches on the left and the seeking switches are set symmetrically, or with corresponding switches occupying similar positions, there is no current path from the relay coil to the ground. In this condition, the relay remains unenergized and the motor does not run.

When any one of the control switches is set to a position different from that of the corresponding seeking switch, the motor relay is energized and the motor is started. The motor continues to run until the seeking switches,

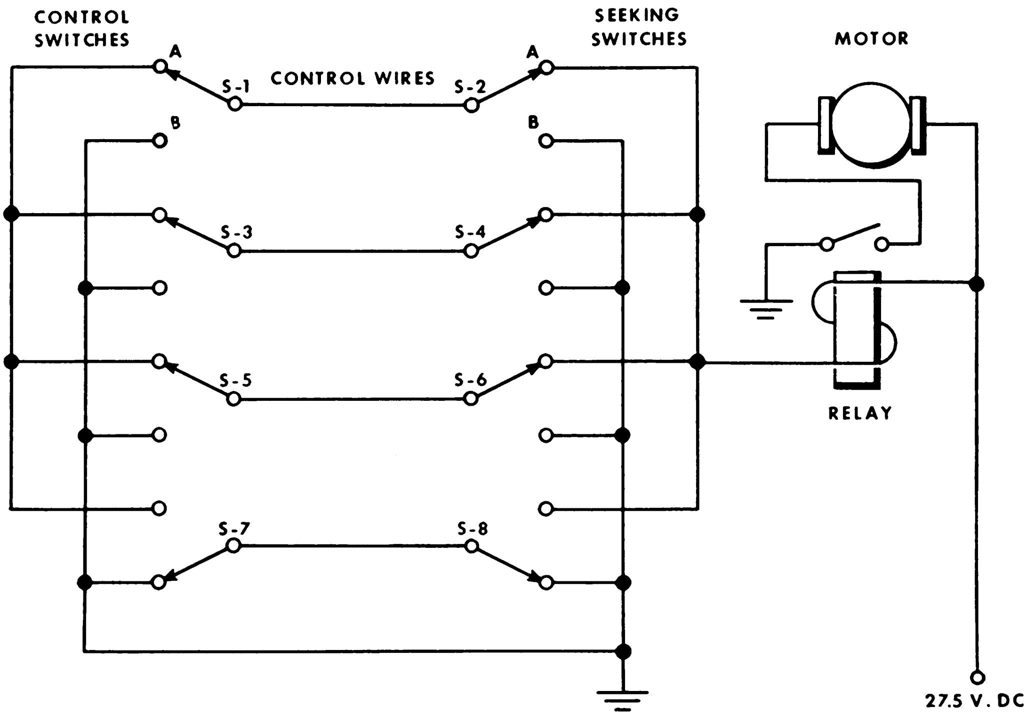


Figure 9-25.—Autopositioner basic diagram.

which are repositioned by the motor, reach a setting similar to those of the control switches. This arrangement stops the motor by opening the relay circuit.

A simplified functional diagram of an autopositioner unit is shown in figure 9-26 which indicates the elements controlled by the open-circuit seeking principle.

The basic elements of the autopositioner are a motor with a gear reduction train, a slip clutch, a rotary shaft to which is fastened a notched stop wheel, a pawl which engages the notches of the stop wheel, a relay for operating the pawl and controlling the motor, and a set of electrical contacts comprising the control system.

The cycle of operation of the autopositioner unit is as follows:

1. The system is at rest with the control and seeking switches in corresponding positions.
2. The operator changes the setting of the frequency selector knob.
3. The relay is energized, lifting the pawl out of the stop wheel and closing the motor control contacts, starting the motor.
4. The motor drives the autopositioner shaft and the rotor of the seeking switch until a position corresponding to the new position of the control switches is reached. Rotation of the motor shaft sets various switches and tuning elements in the receiver-transmitter. When the setting corresponding to the selector position is reached, the open-circuit seeking switches correspond to the control switches. The relay circuit is opened, the pawl engages the stop wheel and the control shaft is brought to a quick stop. The motor coasts to a stop, dissipating the rotating energy in the slipping clutch.

RADIO SET AN/ARC-27A

The equipment bearing the designation AN/ARC-27A is a modification of AN/ARC-27. An installation of AN/ARC-27A contains the same type of receiver-transmitter unit employed in AN/ARC-27. The principal difference between the two sets pertains to the control system in use.

The list of basic units in the AN/ARC-27 installation includes one or two receiver-transmitters, one or two C-626/ARC-27 control boxes, one optional control unit for use by the pilot, and the required mounting racks. The AN/ARC-27A basic units consist of one or two receiver-transmitters, the necessary mountings, and one of the following control units: C-1015/ARC-27A; C-1024/ARC-27A

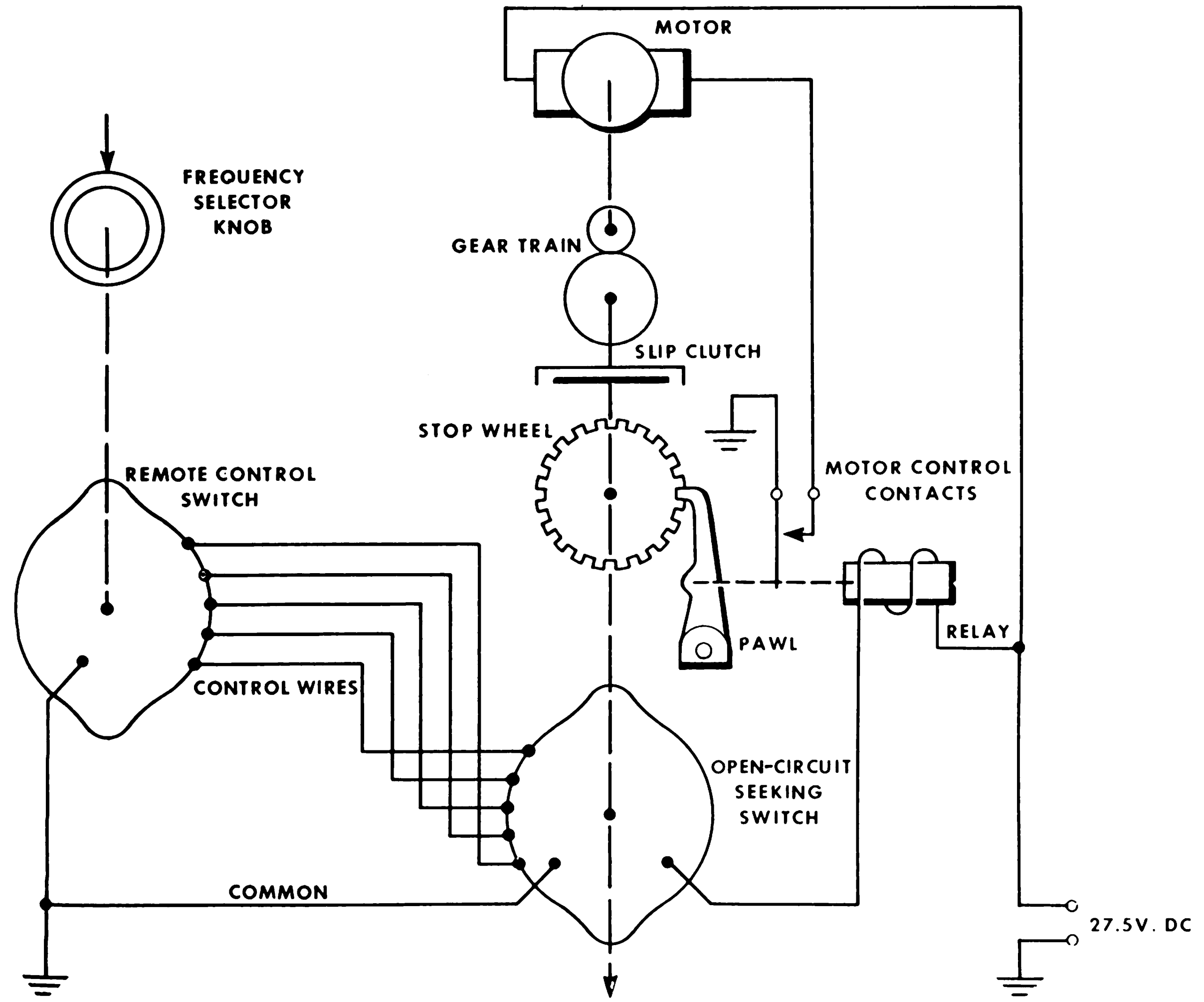


Figure 9-26.—Simplified functional diagram of an autopositioner unit.

or C-1025/ARC-27A. (EMC 18-57 changed certain of these designations to C-1703, C-1704, and C-1705, respectively.)

Either radio set is capable of providing transmission and reception on any one of 1,750 channels in the band of 225 to 399.9 megacycles. And it is also possible to monitor one predetermined guard channel frequency. In both equipments, the control units permit manual selection of any usable frequency within the frequency range of the system. In AN/ARC-27 sets, selection of one of eighteen preset channels or of the guard channel is possible. In the AN/ARC-27A equipment, selection can be made of any one of twenty preset channels or of the guard frequency.

In the operation of the AN/ARC-27 set, the frequencies of the preset channels are determined by settings made at the C-626/ARC-27 control unit which is usually mounted in the radio operator's compartment. In the AN/ARC-27A installation, the preset channel settings are made at the pilot's control unit, which is one of the three listed above. All of the AN/ARC-27A control boxes permit selection of automatic direction finding operation in addition to frequency selection; and no provision is made in any of them for tone transmission.

QUIZ

1. A disadvantage of VHF communications is
   a. excessive weight of equipment
   b. line-of-sight propagation
   c. equipments are not reliable
   d. high power consumed from power source

2. The type of transmission produced by the ART-13 transmitter is
   a. MCW
   b. CW
   c. voice modulated
   d. all of the above

3. The ARC-38 transceiver uses
   a. one stage of RF amplification
   b. all fixed tuned IF amplifiers
   c. two stages of RF amplification
   d. all variable IF amplifiers

4. The correct value of resistance to use when measuring the receiver sensitivity of the ARC-27 is
   a. 52 ohms
   b. 30 ohms
   c. 520 ohms
   d. 300 ohms

5. Automatic tuning systems are
   a. a feature of all communication equipments
   b. a constant source of trouble
   c. a feature of airborne equipment
   d. completely free of troubles

6. The modulator stage for the ART-13 transmitter is
   a. a single-ended stage
   b. a push-push stage
   c. a push-pull stage
   d. none of the above

7. Low-frequency IF amplifiers are used in the ARC-38 to give
   a. adjacent channel selectivity
   b. image frequency rejection
   c. increased fidelity
   d. better isolation to the second detector

8. The frequencies produced by the spectrum system of the ARC-27 are in
   a. 1 mc. steps
   b. 0.1 mc. steps
   c. 10 mc. steps
   d. 100 mc. steps

9. The AIC-15 intercommunication system differs from other systems because it
   a. has fewer units
   b. can be used with a wire recorder
   c. is used in large aircraft only
   d. uses transistors and crystal diodes

10. The two B+ voltages supplied for the ART-13 are produced by
    a. two dynamotors
    b. two inverters
    c. one inverter with dual windings
    d. one dynamotor with dual windings

11. In the ARC-38, isolation of the detector from the IF amplifiers is accomplished by the use of
    a. low IF frequency
    b. a cathode follower
    c. transformer coupling
    d. impedance coupling

12. The guard receiver of the ARC-27 has
    a. double conversion
    b. single conversion
    c. triple conversion
    d. a TRF system

13. The number of control boxes that may be used with the AIC-15 system is
    a. four
    b. eight
    c. thirteen
    d. any of the above

14. The ARC-2 transceiver operates in the
    a. UHF range
    b. HF range
    c. VHF range
    d. LF range

15. The ARC-1 transceiver operates in the
    a. UHF range
    b. MF range
    c. LF range
    d. VHF range

16. Intermediate frequencies of 20-30 mc. are used in the ARC-27 to
    a. increase image frequency rejection
    b. give adjacent channel selectivity
    c. prevent shunting of the second detector
    d. all of the above

17. The ARR-41 receiver may be used to receive
    a. unmodulated CW signals
    b. amplitude-modulated signals
    c. frequency-shift-keyed radio teletype
    d. all of the above

18. The master oscillator in the ARC-2 is in operation
    a. during transmit and receive
    b. during receive only
    c. during transmit only
    d. only on the high-frequency end

19. The squelch circuit in the ARC-1 is used to
    a. limit the audio signal
    b. cut off the audio amplifier
    c. limit IF signals
    d. limit RF signals

20. One of the benefits of double conversion in the ARR-41 is to
    a. increase gain
    b. decrease number of stages used
    c. increase band pass
    d. prevent frequency reflections to antennas

21. Maximum output power of the ARC-38 transceiver on transmit is
    a. produced at altitudes in excess of 50,000 feet
    b. limited by the type of antenna coupler
    c. produced at all altitudes up to 50,000 feet
    d. never used because the antenna is not tunable

22. One advantage of UHF equipment over lower frequency equipments is
    a. longer range
    b. fewer frequencies to tune
    c. lower noise factor
    d. none of the above

23. The BFO of the ARR-41 receiver feeds its signal to the
    a. RF amplifier
    b. input of last IF amplifier
    c. input to the second detector
    d. input to the first audio amplifier

24. The ARC-38 may be divided into the following sections
    a. transmitter, receiver, and control
    b. receiver, transmitter, and memory drum
    c. transmitter, receiver, and power supply
    d. receiver, transmitter, and coupling section

25. The type of propagation used with the ARC-27 is
    a. sky wave
    b. line-of-sight
    c. ground wave
    d. reflected wave

CHAPTER 10

AIRBORNE COMMUNICATION EQUIPMENT--CONTINUED

Single Sideband Radio Equipment

Single sideband is not a new method of radio communication. It was first conceived in 1915, and has been in use since 1927. The decided advantages offered by SSB (single sideband) makes it desirable to develop this method of communication with the possibility that it will eventually replace the DSB (double sideband) in present use.

Production of SSB units has been delayed mainly because of design obstacles affecting the high degree of stability required in both the transmitter and receiver units. Modern techniques of manufacture have perfected oscillators and filter circuits with sufficient stability and accuracy to make SSB feasible. In the several years SSB has been in use in the Naval Communications Systems, it has produced highly satisfactory results.

To aid in understanding SSB, this discussion will present a review of amplitude modulation and show a comparison between SSB and present-day DSB operation. SSB is amplitude modulation with one sideband and the carrier removed. The purpose of this discussion is to explain how an SSB signal is generated, transmitted, and received, and also present the advantages of the SSB method over the DSB method.

There are several methods of obtaining SSB operation. However, the one discussed here is the true SSB. Other methods are used. Television, for example, employs a method of transmission whereby most, but not all, of one sideband is suppressed (removed). In some installations the carrier is greatly but not entirely suppressed. The greatly suppressed carrier is called a "pilot carrier." The pilot carrier will be used in the receiver for reference and automatic control. True SSB has one sideband and the carrier is entirely suppressed, and only the remaining sideband is transmitted.

MODULATION

With no modulation, the output of a transmitter is an oscillating wave of radio energy that has a frequency corresponding to the station's transmitting frequency. This is usually referred to as an unmodulated carrier. The unmodulated carrier is a continuous wave (CW) signal and occupies no bandwidth in the frequency spectrum. Any single radio-frequency (RF) signal can be represented by an infinitely thin vertical line on a plot of amplitude versus frequency. In figure 10-1, the solid line represents the frequency in kilocycles, while the dotted line is merely a measure of the amplitude or signal strength of the specific frequency.

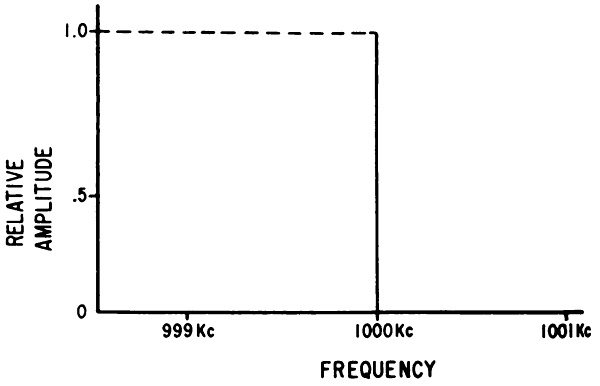


Figure 10-1.—Frequency spectrum of an unmodulated carrier.

If a radio wave is to convey voice intelligence, some feature of the wave must be varied in accordance with the voice intelligence to be transmitted. Amplitude modulation consists of varying the amplitude of radiofrequency waves at an audio rate. Amplitude modulation may be defined as the variation of the strength of the RF output of a transmitter at an audiofrequency, as diagramed in figure 10-2. In other words, the RF energy has to increase and decrease in power, according to the audio (sound), frequencies. If the audiofrequency is high, the radiofrequency must vary in amplitude more rapidly than if the audiofrequency is low. At the receiver, if the audio note is loud in volume,

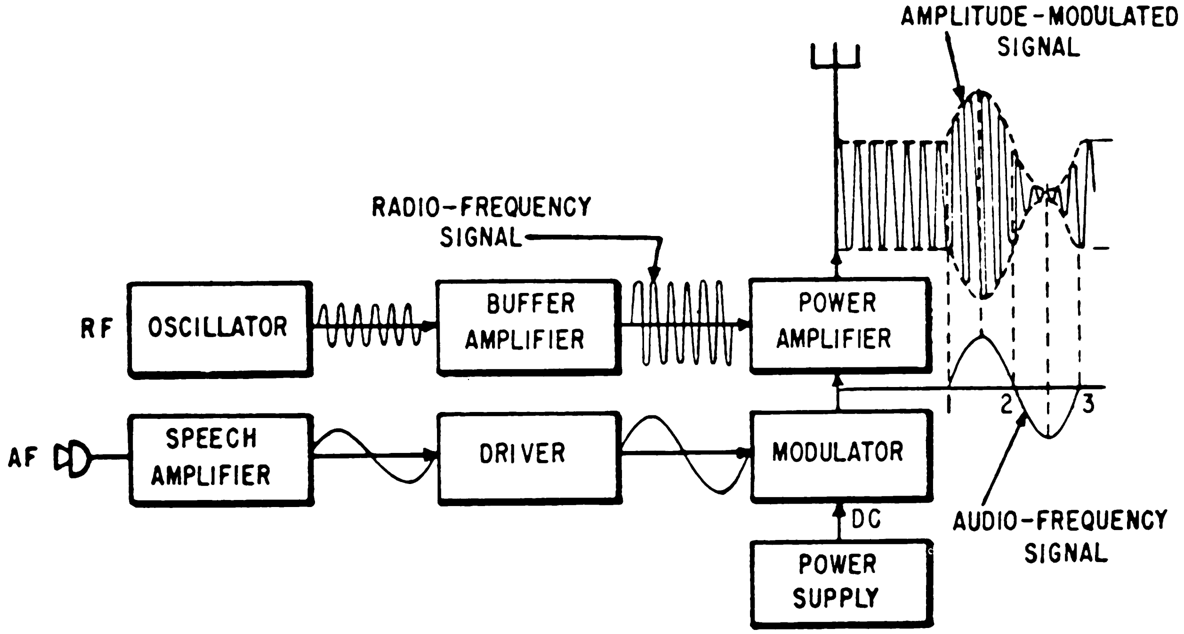


Figure 10-2.—Conventional AM transmitter.

the radiofrequency energy must be increasing and decreasing by a larger percentage than if the audio note were soft. Thus, the RF variations must correspond in every respect with the AF variation.

There are a number of methods for producing amplitude modulation, such as plate modulation, grid modulation, screen modulation, and so forth. Modulation is also classified as high-level or low-level; depending on where the modulator signal is impressed on the RF carrier. High-level modulation takes place at the final power amplifier; low-level modulation takes place before the final power amplifier.

High-Level Modulation

High-level plate modulation is so named because the audio signal is injected in the plate circuit of the final amplifier, as shown in figures 10-2 and 10-3. The plate circuit of the triode class C power amplifier, *V*1 of figure 10-3, is tuned to a resonant frequency of 1 megacycle which will be the transmitted carrier frequency. The plate current is 100 ma. and the plate voltage supply is 1,000 v. The grid input driving voltage is produced by an RF oscillator and a buffer amplifier (used to isolate the oscillator from the power stage). This is shown in the block diagram of figure 10-2.

An audio signal of approximately 1,000 volts (peak) having a sine waveform and a frequency of 1,000 cycles per second is produced by the AF section, shown as a block diagram at the right in figure 10-3, and appears as an output of the modulation transformer M. This audio output voltage is in series with the RF tank circuit, LC, and the plate power supply or B+ voltage E_B.

Before an audio-modulation signal is introduced, the RF signal applied to the grid of *V*1 causes the triode to conduct periodically. During each conducting period, capacitor C charges. When the grid swings below cutoff, the triode stops conducting and the capacitor discharges through the coil.

The exchange of energy between the coil and capacitor accounts for the RF voltage developed across the tank. In this example, the voltage across the tank capacitor C, which receives its charge from the 1,000-volt B+ supply is 1,000 volts, neglecting losses.

Plate voltage varies above and below 1,000 volts or between 2,000 volts and 0 volts as the capacitor varies between +1,000 and -1,000 volts. The value of the plate voltage is above that of the B+ supply during the part of the cycle when the grid voltage is below cutoff and the triode is not conducting. Plate voltage is below the B+ supply voltage during the time the grid is above cutoff and the triode is conducting.

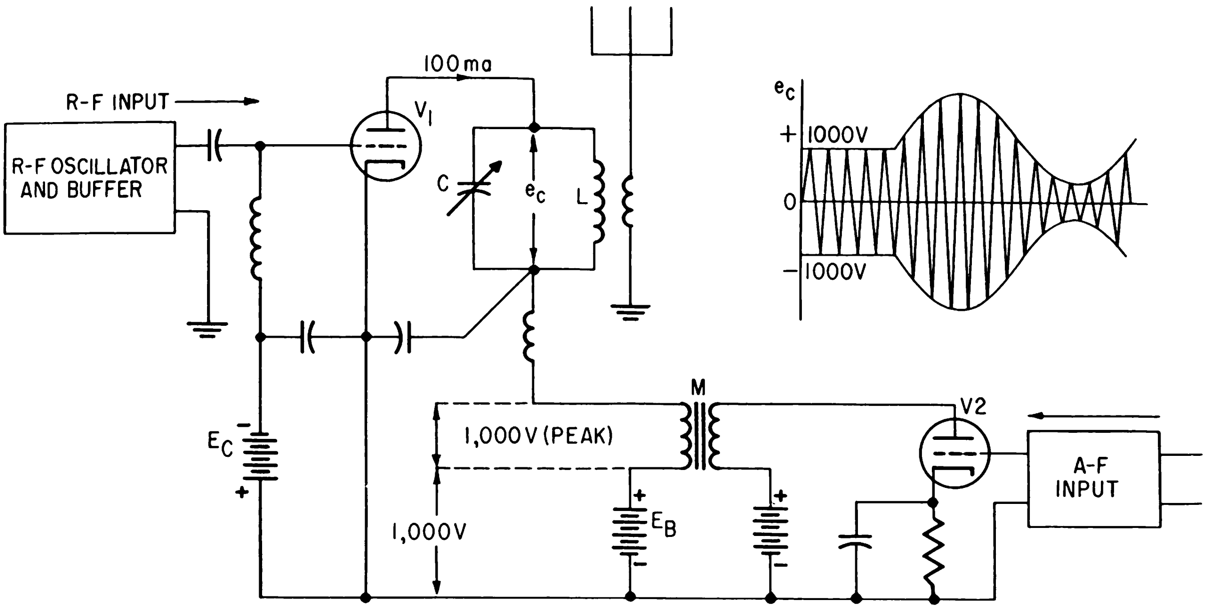


Figure 10-3.—Simplified diagram for high-level plate amplitude modulation.

The output of the transmitter is an unmodulated carrier.

Now, assume that the AF (1 kc.) sinusoidal voltage is introduced at M in series with the RF tank and the B+ supply. The frequency of the RF voltage developed across the plate tank is 1,000 times the audiofrequency. Thus the time for one complete audio cycle is long enough to include 1,000 cycles of RF energy in the tank circuit, LC. Consider that portion of the AF cycle in which the voltage is gradually rising according to the sine wave variation so that the polarity aids the voltage of the B+ supply. For 250 cycles of radiofrequency (one-quarter of one AF cycle), the total voltage available for charging capacitor C in the plate tank circuit is increasing from 1,000 volts to a maximum of 2,000 volts. Assume that the capacitor charges to 2,000 volts. The plate voltage at the end of the 250 RF cycles is a maximum of 2,000 + 2,000 or 4,000 volts. Thus with 100 percent modulation, considering both positive and negative peaks, the value of the peak-to-peak voltage across capacitor C is approximately double the peak-to-peak value it would have without modulation, or four times the B+ supply voltage.

The tank voltage starts to decrease between the 250th RF cycle and the 500th RF cycle, as the AF voltage falls from a maximum of 1,000 volts to zero volts during this period. From the 500th to the 750th RF cycle, the polarity of the AF voltage is reversed and reaches a maximum negative value at the 750th RF cycle, and the tank capacitor charges up to the difference voltage between the 1,000 volt B+ supply and the instantaneous AF value. At the instant the AF voltage is maximum negative (-1,000 volts at the 750th RF cycle), the tank capacitor is not charging at all, the tank voltage is zero, and the RF output energy is zero. The AF voltage starts to rise from maximum negative to zero and the opposition that it offers to the power supply voltage (B+) is reduced. The plate tank capacitor starts charging again, and the RF tank current again gradually increases during the subsequent 500 RF cycles of operation.

The transmitting antenna is coupled to the tank, and the instantaneous antenna current increases and decreases in accordance with the tank current variation. The signal transmitted is 1 mc. modulated at 1 kc.

Percentage of Modulation

The degree of modulation is expressed by the percentage of maximum amplitude deviation from the normal amplitude of the RF carrier. The effect of a modulated wave as measured by receiver response is proportional to the degree of percentage of modulation.

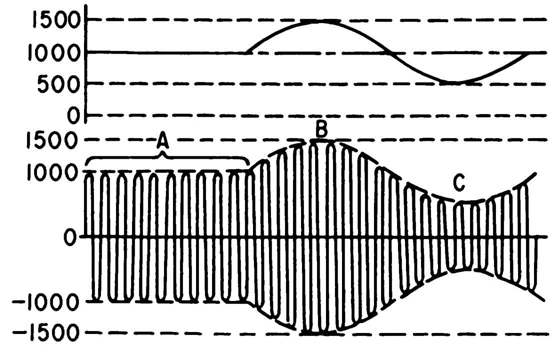
The percentage of variation of the total voltage of the final RF amplifier stage in high-level plate modulation will depend upon the ratio of AF to unmodulated RF plate voltage. For example, if the plate voltage of the RF amplifier is 1,000 volts, and the AF voltage is 500 volts, the two voltages will add (when they are acting in the same direction) to give 1,500 volts. They will subtract (when they are acting in the opposite directions) to give 500 volts. The modulated plate voltage of the RF amplifier will vary between 500 and 1,500 volts at the audio rate. This is illustrated in figure 10-4 (A). Since the variation is one-half of the RF voltage variation of 2,000 volts, the transmitter is said to be modulated 50 percent. Figure 10-4 illustrates different percentages of modulation.

It is important that the transmitted RF energy be kept as close to 100 percent modulation as possible because the output of a detector in a radio receiver varies with the amplitude of the AF component of the received signal. This is why a comparatively low-power station, well modulated, will often produce a stronger signal at a given point than a much higher powered but poorly modulated transmitter located at the same distance from the receiver. The useful limit for the percentage of modulation is 100 percent. Overmodulation, such as shown in figure 10-4 (C), causes severe distortion in the signal.

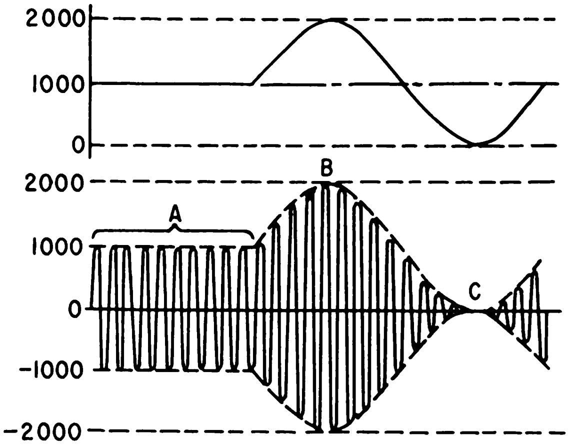
SIDEBANDS

The circuit of figure 10-3 may be regarded as being composed of two sources of signal voltage and a common load in series. One source is the RF generator, the other is the AF generator, and the load is the resonant tank circuit coupled to the antenna.

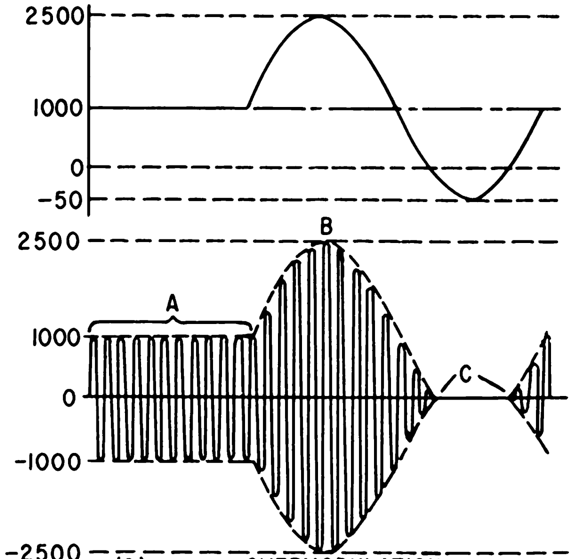
It is well known that when two frequencies are introduced into a circuit having a common nonlinear load impedance (the class C amplifier), these two frequencies combine to produce two additional frequencies. These additional frequencies are called sidebands or sideband frequencies. They are the sum and difference frequencies of the RF and AF generators. This is not the complete picture. The nonlinear device (the class C amplifier) will heterodyne or "beat" to produce a theoretically infinite number of frequencies in the output. These exist at the plate of *V*1 in figure 10-3.



50% MODULATION
(A)



100% MODULATION
(B)



(C) OVERMODULATION

Figure 10-4.—Percentage of modulation.

The infinite number of frequencies fall into four groups:

1. Frequencies identical with those introduced. The amplitude of the current of each frequency in this group is proportional to the amplitude of the voltage of the same frequency in the input wave.
2. Frequencies which are twice the frequency of each component in the input wave (even order harmonics). In this example complex waveform inputs are being discussed. Harmonics other than the second are produced, but they are very weak and easily dispensed with as described below.
3. Frequencies which are equal to the sum of each frequency in the input with every other frequency in the input. In this case, carrier frequency plus modulating frequency, or upper sideband frequency.
4. Frequencies which are equal to the difference of each frequency in the input from every other frequency in the input. In this case, carrier frequency minus modulating frequency, or lower sideband frequency.

In this example of the principle of modulation, the two frequencies, 1,000,000 cycles (RF) and 1,000 cycles (audio), are impressed on the nonlinear impedance. The following distortion frequencies will also exist: 2,000,000 cycles, 999,000 cycles, 1,001,000 cycles and 2,000 cycles. All of these frequencies can be found to exist at the plate of *V1* in figure 10-3.

It was mentioned before that the resonant tank circuit coupled to the antenna load is a nonlinear impedance. Since the circuit is tuned to 1,000 kc., it can efficiently radiate only those frequencies in the neighborhood of the one to which it is tuned.

When the carrier plus its upper and lower sidebands are transmitted through a resonant tank circuit, and with the tank resonant at the carrier frequency, each component of a pair of sideband frequencies will be shifted in phase. One is advanced and the other retarded by equal amounts as shown in figure 10-6. The curves show how the carrier and sidebands combine graphically and algebraically to produce an amplitude-modulated wave with 100 percent modulation by a steady tone.

Figure 10-5 illustrates that the only frequencies contained in the total output that fall within the range of the resonance curve are the 1,000-, the 999-, and the 1,001-kc. frequencies. The transmitter final amplifier plate resonant circuit is tuned to the carrier frequency and it attenuates all frequencies present at the plate except the carrier and its upper and lower sidebands.

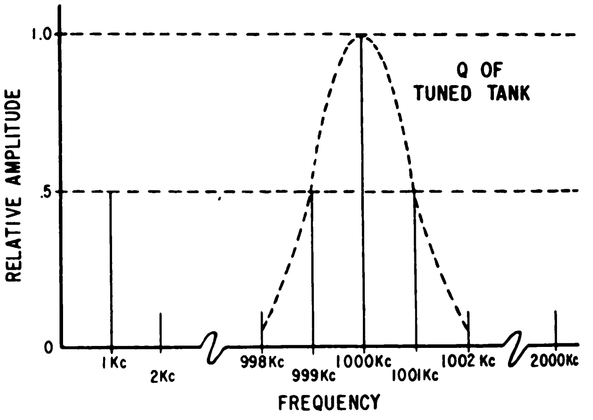


Figure 10-5.—Power amplifier plate circuit selectivity curve.

Neglecting all other frequencies present at plate of the RF power amplifier but the last three, and combining these, an amplitude-modulated wave is obtained. Figure 10-6 (D) illustrates this graphically.

In actual practice for communication, the modulating wave is usually a complex wave instead of a simple sinusoidal one. In the case of speech or music, the modulating wave may be a wide band of frequencies. For example, if the modulating wave should include frequencies throughout the range of 100 to 5,000 cycles, and the carrier is still 1,000kc., (1,000,000 cycles), then two sidebands would

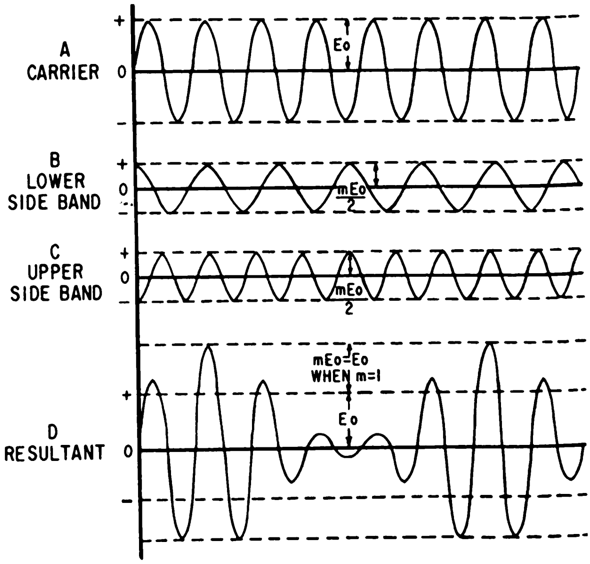


Figure 10-6.—Steps of 100 percent modulation.

be produced. The upper sideband would be from 1,000,100 to 1,005,000 cycles, and the lower one would be in the range of 995,000 to 999,900 cycles. For each component of the original complex audio input band there would be a corresponding component in both the upper and lower sidebands.

Since this chapter article will be dealing with single sideband, the discussion will now start referring to amplitude modulation as double sideband (DSB) to distinguish it from single sideband. Double sideband is a better term because, instead of transmitting only one frequency, the antenna is actually radiating two frequency bands and the carrier frequency. These are close together and within the bandwidth of the RF amplifier resonant circuit.

DOUBLE SIDEBAND

Power Relations in the DSB Transmitter

The amount of audio power required to modulate a DSB transmitter depends on the percentage and type of modulation. To modulate a carrier 100 percent with a single sine wave of audiofrequency requires an audio power equal to one-half of the RF carrier power. With 100 percent modulation, the amplitude of each sideband is one-half the amplitude of the RF carrier. Power is proportional to current squared; thus each sideband carrying one-half the current of the carrier contains one-fourth the power. (See fig. 10-7.) Therefore, the power required with modulation is one and one-half times the normal unmodulated power. Using voice modulation, the greater portion of the AF components will not modulate the carrier 100 percent, so that the power required for 100 percent voice modulation is considerably less than for single tone modulation.

A modulated RF amplifier must handle peak currents which are twice the normal (unmodulated) magnitude. This means that the amplifier must be capable of handling up to four times the power it dissipates during steady intervals of unmodulated carrier output.

Bandwidth Requirements for DSB

Since a DSB propagation has sidebands on each side of the carrier, the transmission of

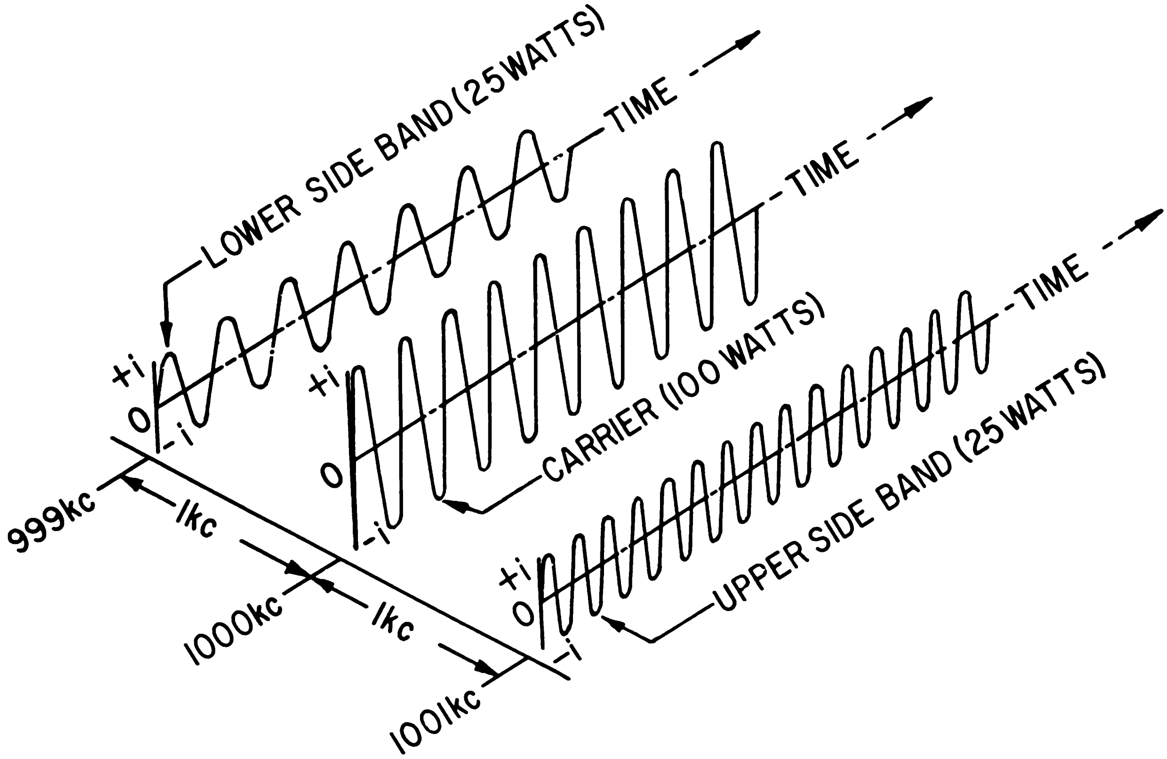


Figure 10-7.—Carrier and its sideband frequencies when the carrier is modulated 100 percent by a 1-kc. tone, and losses are neglected.

information by DSB requires the use of a band of frequencies rather than a single frequency. Music contains frequency components as high as 15,000 cycles per second, so that music modulating a carrier produces sideband components extending to 15,000 cycles on each side of the carrier frequency.

Local DSB broadcast stations are allocated a total bandwidth of only 10 kc. (5 kc on each side of carrier frequency). Therefore, audiofrequency above 5 kc. cannot be transmitted without possibly causing interference between stations. At a carrier frequency of 1 mc., 10 kc. is 1 percent of the carrier frequency.

Naval DSB communication sets do not need high fidelity and may operate with a relatively narrow bandwidth. For example, some receivers utilize a narrow, adjustable bandwidth of only a few tenths of 1 percent carrier frequency. A narrow bandwidth reduces noise and increases selectivity.

Reception of DSB

When the incoming wave, consisting of a carrier plus its upper and lower sidebands, arrives at a receiver, it must be converted back to its original audiofrequency in order to be intelligible to the ear. This process is called demodulation. The overall result of the DSB communication system depends upon the efficiency of the modulation and demodulation processes. Any unwanted frequencies which may appear in the output of the receiver will give the same effect as nonlinear distortion in transmission over any audio channel.

However, nonlinear distortion is used and is an inherent part of the process of detection or demodulation. At this time it is apparent that a distinction should be drawn between the distortion which enables the signal to be converted to new frequency bands and back again, and the distortion which produces new unwanted frequencies in the audio output which cannot be eliminated.

The former is desirable, the latter always undesirable.

When the carrier and sideband frequencies are transmitted through a resonant circuit, resonant at the carrier's frequency, each component of a pair of sideband frequencies will be shifted in phase. One is advanced and the other retarded by equal amounts. Due to propagation effects, the two sidebands of the DSB system may be shifted in phase relative to each other and the carrier so that at the receiver demodulation components add randomly rather than in phase. This creates unwanted distortion.

New frequency components are also created whenever the shape of a wave is changed or distorted. This happens during amplification, rectification, modulation, and demodulation. If a pure sine wave is amplified, the small nonlinearities of the amplifier add distortion in the form of second and higher-order harmonics. When a pure sine wave is rectified, the output contains a d-c component plus harmonics of the original frequency produced by the nonlinearity of the rectifier.

Demodulation

It has been stated that new frequencies are created in the process of modulation. For example, if a 1-kc. signal modulates a 1,000-kc. carrier, sidebands of 1,001 kc. and 999 kc. are created.

If a 1,000-kc. signal were made to modulate the 999-kc. sideband an upper frequency of 1,999 kc. and a lower frequency of 1 kc. would be created. Also, if the 1,000-kc. signal were made to modulate the 1,001-kc. sideband, an upper frequency of 2,001 kc. and a lower frequency of 1 kc. would be created. Provided that propagation did not cause any shift in their phases relative to each other, the 1-kc. signals will be in phase. Note that 1 kc. is the original modulating frequency. This is the mechanism of the demodulation action. A carrier frequency and received sideband frequencies modulate one another and produce new frequencies, among which is the desired audiofrequency.

Sum and difference frequencies are important in the modulation and demodulation of DSB waves. To produce sum and difference frequencies, it is necessary to change the shape of the input waves. This is done by impressing the waves on a nonlinear device. DSB modulators and demodulators are always nonlinear devices, such as class C amplifiers, and diodes.

It has been pointed out that in DSB systems there exist two sidebands that are demodulated in the receiver to produce a single audio signal that carries the voice intelligence heard in a speaker or headset. That is, of course, if their phase has not shifted due to multipath sky-wave propagation. One sideband may shift slightly in phase due to multipath transmission, thereby causing near cancellation of the other sideband. This produces distortion and loss of intelligibility. Similar results are obtained if the carrier experiences fading or a slight phase shift.

In the process of demodulation, it was illustrated that a signal equal to the original audio signal was produced from two sources; one by each sideband beating with the carrier. Since either sideband contains all the intelligence, then one sideband may be removed by a filter without interfereing with the overall transmission of the original audio signal. The total RF transmission band covered would be cut in half if one sideband were eliminated, with the result that more channels could be operated within a given range of frequencies. In addition, distortion caused by propagation effects would be eliminated.

The only purpose of the carrier is to serve in the demodulation of the incoming signal. Since the carrier is used in the demodulation process, it is possible to eliminate the carrier at the transmitter and reintroduce it at the receiver.

CARRIER-SUPPRESSION AND SINGLE-SIDEBAND SYSTEMS

The carrier may be eliminated or suppressed by some arrangement such as the balanced-modulator circuit shown in figure 10-8.

The carrier voltage is applied to the two modulator tubes (*V*1 and *V*2 are nonlinear devices) in the same phase (push-push) while the modulator-signal voltage is applied in opposite phase (push-pull) to the two grids by means of the center-tapped transformer. The outputs in the plate circuits of the two tubes are combined through a transformer with a center-tapped primary in such a way that voltages applied to the two grids in push-push cancel each other in the output (plate circuit); whereas voltages applied to the two grids 180 degrees out of phase (push-pull) are added in the output. Thus, the carrier voltage, which is applied to the two tubes in push-push does not appear in the secondary of the output transformer; whereas the sideband components (audio), which are applied in push-pull, are added in the output. The result is an output that is a modulated wave from which the carrier component has been removed.

The output from the balanced modulator tubes contains three of those four groups of frequencies already mentioned in the discussion of nonlinear devices. These groups are as follows:

Group 1. Those frequencies identical with the components of the signal voltage in the input, but none at the frequency of the carrier.

Group 3. Those frequencies equal to the sum of the carrier frequency and each component in the signal.

Group 4. Those frequencies equal to the difference between the carrier frequency and each component in the signal.

Now that the carrier has been eliminated, all that remains is to eliminate one of the sidebands. This can be accomplished by either the filter method or the phasing method. These methods will be explained after a discussion of the various types of filters.

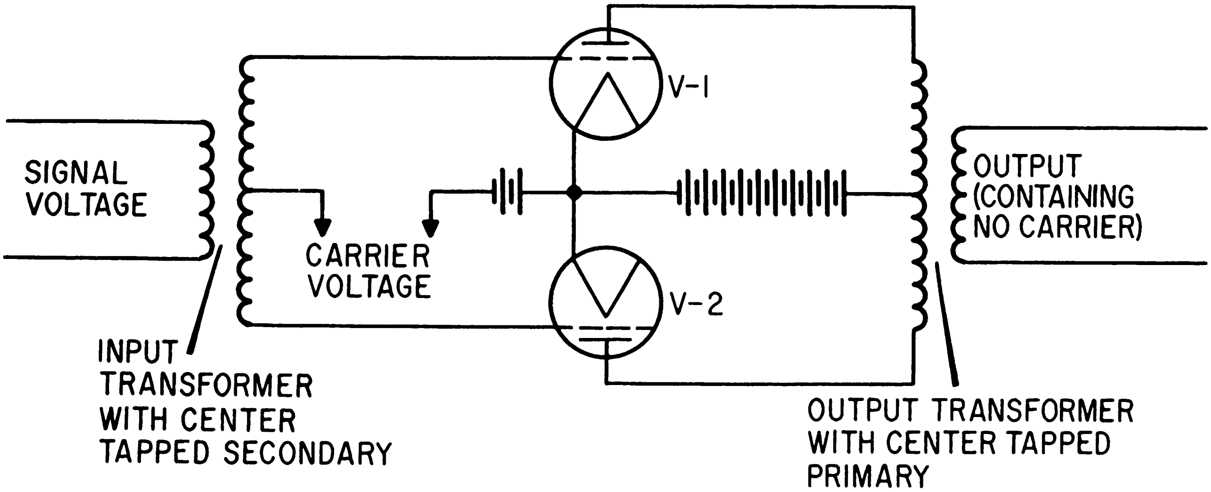

V-1
SIGNAL VOLTAGE
CARRIER VOLTAGE
OUTPUT (CONTAINING NO CARRIER)
V-2
INPUT TRANSFORMER WITH CENTER TAPPED SECONDARY
OUTPUT TRANSFORMER WITH CENTER TAPPED PRIMARY

Figure 10-8.—Simplified balanced-modulator circuit for suppressing carrier without affecting the sidebands.

Both SSB transmitters and SSB receivers require extremely selective bandpass filters in the region of 100 to 500 kilocycles.

In receivers, a high order of adjacent channel rejection is required if channels are to be closely spaced in order to conserve spectrum space. In SSB transmitters, the signal bandwidth must be limited sharply in order to pass the desired sideband and reject the other sideband. The filter used, therefore, must have very steep skirt characteristics (fast cutoff) and a flat bandpass characteristic in order to pass all frequencies in the band equally well. These filter requirements are met by crystal filters, LC filters, and mechanical filters.

Crystal Filters

Until recently, crystal filters used in commercial SSB equipments were in the 100-kc. range. Such filters have excellent selectivity and stability characteristics, but their large size makes them subject to shock or vibration deterioration. Also, their cost is quite high.

Newer crystal filters are being developed that have extended frequency range and are smaller. These newer crystal filters are more acceptable for use in SSB equipment.

LC Filters

LC filters have been used at IF frequencies in the region of 20 kc. However, generation of the SSB signal in this low frequency range requires an additional mixing stage to obtain a transmitting frequency in the high-frequency range. For this reason LC filters are not widely used.

Mechanical Filters

Recent advancements in the development of mechancial filters have led to their acceptance in SSB equipment. Mechanical filters have excellent rejection characteristics, are extremely rugged, and are small enough to be compatible with miniaturization of equipment. Also, to the advantage of the mechanical filter is a Q in the order of 10,000 which is about 100 times the Q obtainable with electrical elements.

Although the commercial use of mechanical filters is relatively new, their basic principles are well established. (Most of this material on the mechanical filter is taken from a BuShips course of instruction based on Collins Radio Company Equipment.)

The mechanical filter is a mechanically resonant device that receives electrical energy, converts it into mechanical vibration, then converts the mechanical energy back into electrical energy at the output. The mechanical filter consists basically of four elements:

1. An input transducer that converts the electrical input into mechanical oscillations.
2. Metal disks that are manufactured to be mechanically resonant at a certain frequency.
3. Coupling rods that couple the metal disks.
4. An output transducer that converts the mechanical oscillations back into electrical oscillations.

Figure 10-9 shows the elements of the mechanical filter. Figure 10-10 shows the electrical analogy of the mechanical filter. In the electrical analogy, the series resonant circuits $L1C1$ represent the metal disks, the coupling capacitors $C2$ represent the coupling rods, and the input and output resistances R represent the matching mechanical loads.

Transducers

The transducer, which converts electrical energy into mechanical energy and vice versa, may be either a magnetostrictive device or an electrostrictive device.

The magnetostrictive transducer utilizes the principle that certain materials can be made to elongate or shorten when in the presence of a magnetic field. Therefore, if an electrical signal is sent through a coil whose core is made of a magnetostrictive material, the electrical oscillation will be converted into mechanical oscillation. The mechanical oscillation can then be used to drive the mechanical elements of the filter, which are the disks.

The electrostrictive transducer utilizes the principle that certain materials, such as piezoelectric crystals, will compress when subjected to an electric current or voltage.

Both types of transducers have a natural resonant frequency. They are manufactured, or "tuned," to be resonant at a specific frequency. Transducers are chosen for a particular application, such as the ability to pass the frequencies of one sideband and reject all other frequencies.

Figure 10-11 (A) is the block diagram of an SSB transmitter that utilizes mechanical filters. Filtering action by the mechanical filter shown in figure 10-9 is accomplished in the following manner. The first bandpass

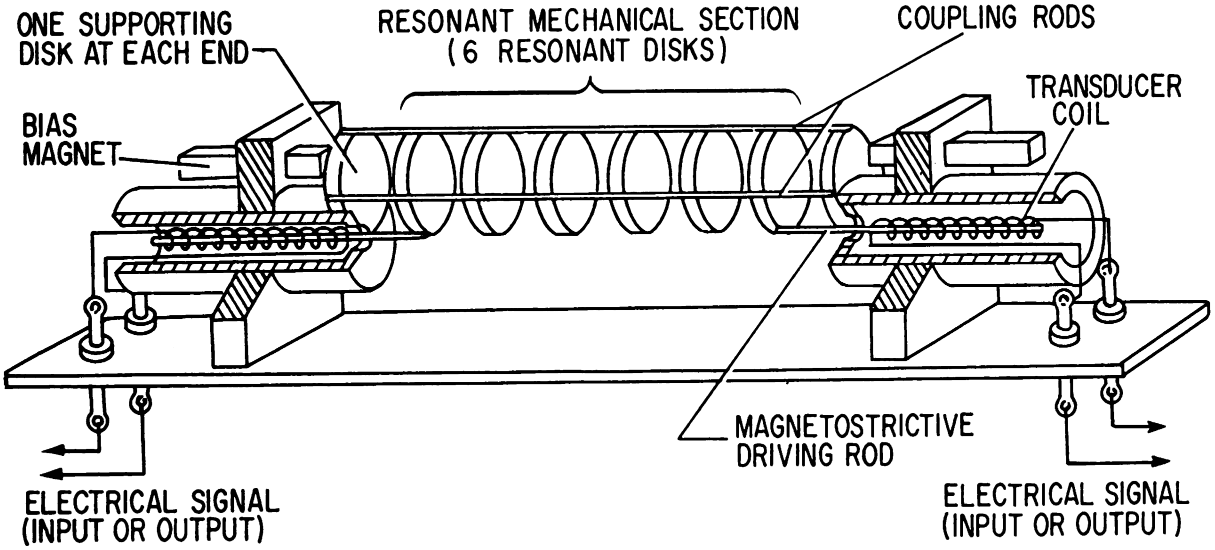

ONE SUPPORTING DISK AT EACH END
RESONANT MECHANICAL SECTION (6 RESONANT DISKS)
COUPLING RODS
TRANSDUCER COIL
BIAS MAGNET
MAGNETOSTRICTIVE DRIVING ROD
ELECTRICAL SIGNAL (INPUT OR OUTPUT)
ELECTRICAL SIGNAL (INPUT OR OUTPUT)

Figure 10-9.—Elements of mechanical filter.

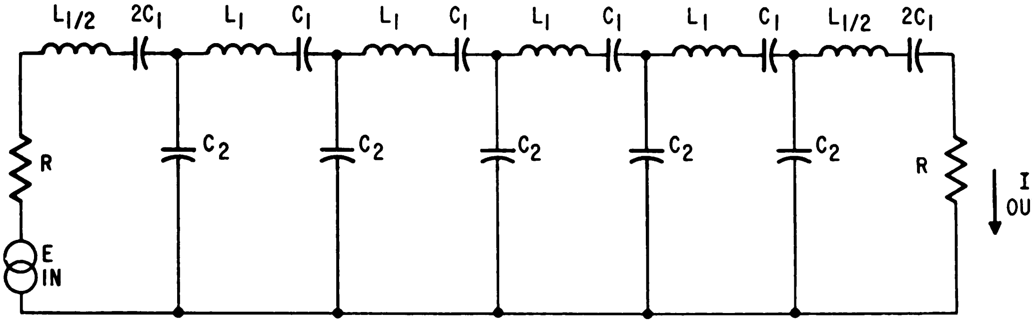


Figure 10-10.—Electrical analogy of a mechanical filter.

filter will receive only the two sidebands of the modulated signal from the low-frequency modulator. (Elimination of the carrier was explained earlier.) The metal disks of the mechanical filter (fig. 10-9) are "tuned" to pass only the frequencies of the desired sideband. Although the transducer driving rod applies the frequencies of both sidebands to the first disk, the vibration of the disk will be greater at its resonant frequency than at the unwanted sideband frequency. Mechanical vibration of the first disk is transferred to the second disk, but a smaller percentage of the unwanted sideband frequencies is transferred. Each time the vibrations progress from one disk to the next disk there is a smaller percentage of the unwanted sideband frequencies transferred. After six disks have been set in motion, virtually all of the unwanted sideband frequencies have been suppressed. The remaining (desired) sideband frequencies are taken off the transducer coil at the terminal end of the filter. It is interesting to note that either end of the filter may be used as the input, and either end used as the output.

In the equivalent circuit (fig. 10-10), the coupling capacitors $C2$ represent the rods that couple the disks. By varying the mechanical coupling between the disks, that is, by making the coupling rods larger or smaller, the bandwidth of the filter is varied.

Because the bandwidth varies approximately as the total area of the coupling rods (in magnetostrictive transducers), the bandwidth can be

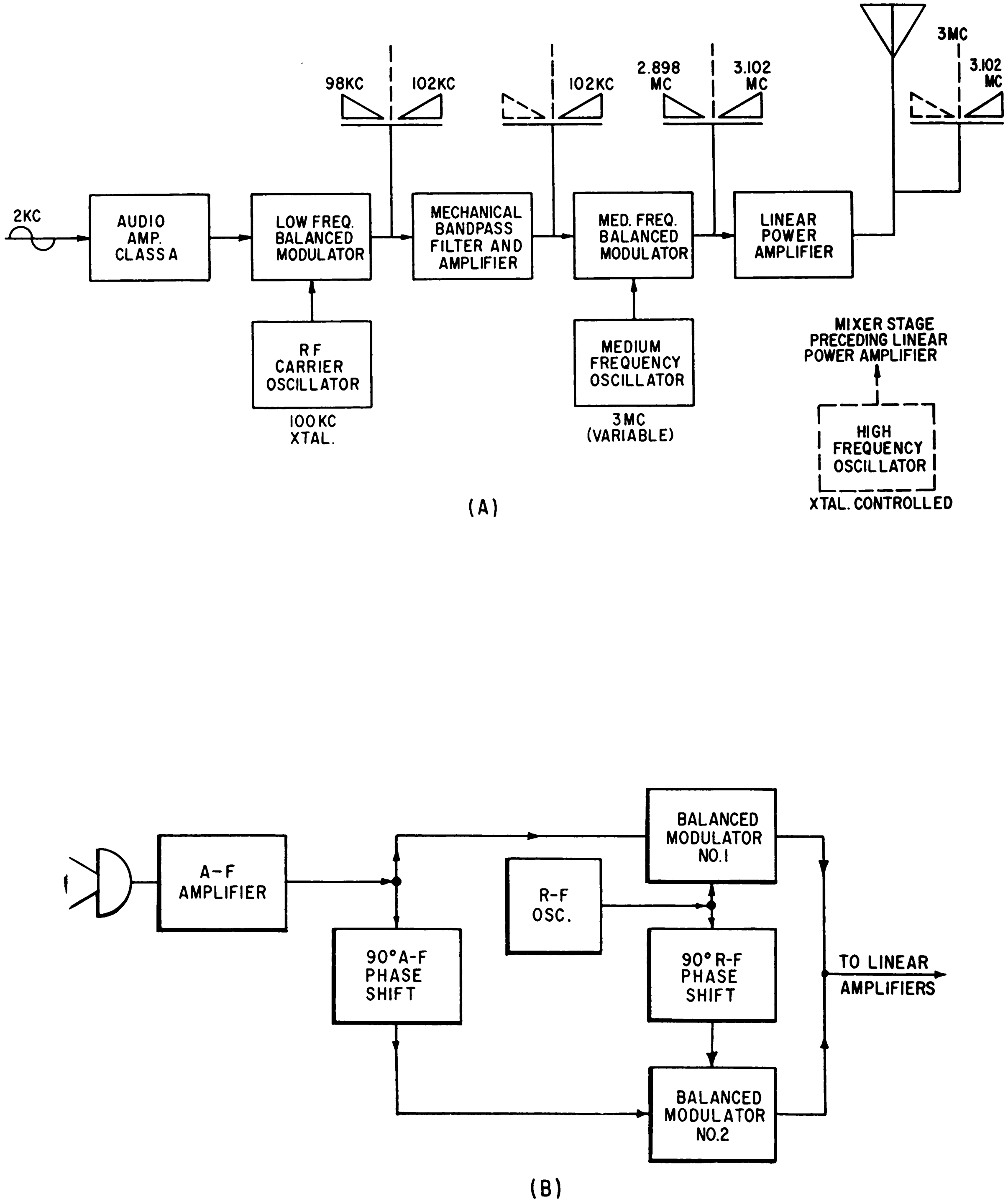


Figure 10-11.—Block diagram illustrating the two principles used in producing SSB transmission.

increased by using either larger coupling rods or more coupling rods. Mechanical filters with bandwidths as narrow as 0.5 kc. and as wide as 35 kc. are practical in the 100- to 500-kc. range.

Filter Method of Sideband Suppression

It is apparent that the most simple and direct means of accomplishing SSB transmission by the filter method would be to filter out the carrier and one sideband of the conventional DSB system. This is not feasible since, if this system were used with conventional DSB transmitter circuits, high-power dissipating filters in the transmitter output stage would be required. This would result in a waste of power. To avoid this, the balanced modulators and filters are used in the low-power stages of a transmitter. The filter is required to accomplish the following:

1. Pass the desired sideband.
2. Limit the bandwidth of the desired sideband to that required for an intelligible communications circuit.
3. Provide adequate suppression of the undesired sideband.
4. Provide some attenuation of any remaining carrier frequency.

The ideal filter characteristics are shown as a solid line in figure 10-12. The solid line represents the ideal filter curve, which would pass only the upper sideband and reject the carrier and the lower sideband. The dotted line represents the filter curve that usually exists, which may vary depending on the type of filter used. A filter having those characteristics would be used as the first filter in figure 10-11 (A). In actual practice such a filter does not exist. But there are some filters that approach the requirements stated above, such as the electromechanical bandpass filter and the crystal lattice filter.

Figure 10-11 (A) is a block diagram showing the use of the balanced modulator and the mechanical filter. For illustration, a single-tone, 2,000-cycle audio signal is used, but in actual practice a complex audio signal would be applied.

The 2-kc. audio signal is amplified and mixed in the balanced modulator with a 100-kc. carrier. Remember, the carrier does not appear in the output of the balanced modulator. When mixed, however, the sum and difference frequencies do appear in the output. The 2-kc. (fundamental) signal is so far from the frequency of the mechanical filter that it can be ignored. As illustrated, the two sidebands are applied to the mechanical filter. The dotted line shows where the carrier has been removed. Removal of the lower sideband is accomplished by the mechanical filter.

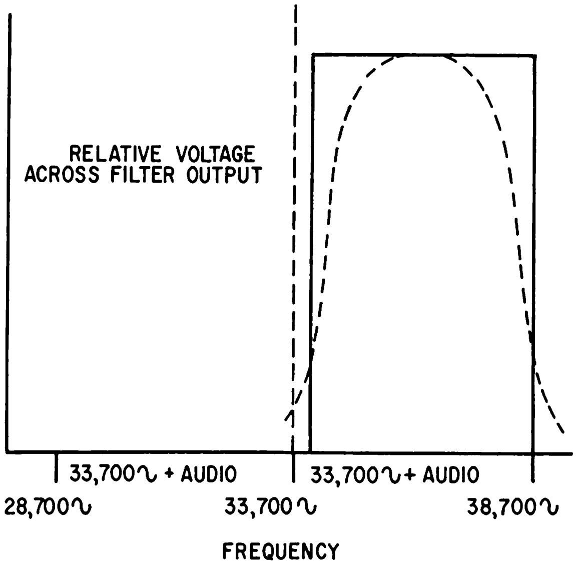


Figure 10-12.—Filter characteristics.

Because the remaining sideband is too low in frequency, it must be mixed again with a 3-mc. signal to raise it to the desired transmitter frequency. Again, the balanced modulator removes the two fundamentals and applies the two new sidebands (sum and difference) to the linear power amplifier. The input and output circuits of the linear power amplifier are tuned to reject one sideband and pass the other to the antenna for transmission.

In actual practice a high-frequency oscillator, shown in dotted lines in figure 10-11 (A), would be used prior to the power stage. Also, the medium frequency oscillator is variable so that transmitter output frequency can be varied.

The power stage may be two or three power amplifiers. Since the carrier is suppressed in the balanced modulators and one sideband is removed by the filters, ALL OF THE TRANSMITTED ENERGY IS IN THE SINGLE SIDEBAND. This is sometimes called "talk power." Since only the talk power is radiated, it follows that when no audio is being applied to the transmitter there is no transmitter output, even though the transmitter is fully activated.

Since only one sideband is required for signal transmission, single sideband transmitters may be used to transmit two messages,

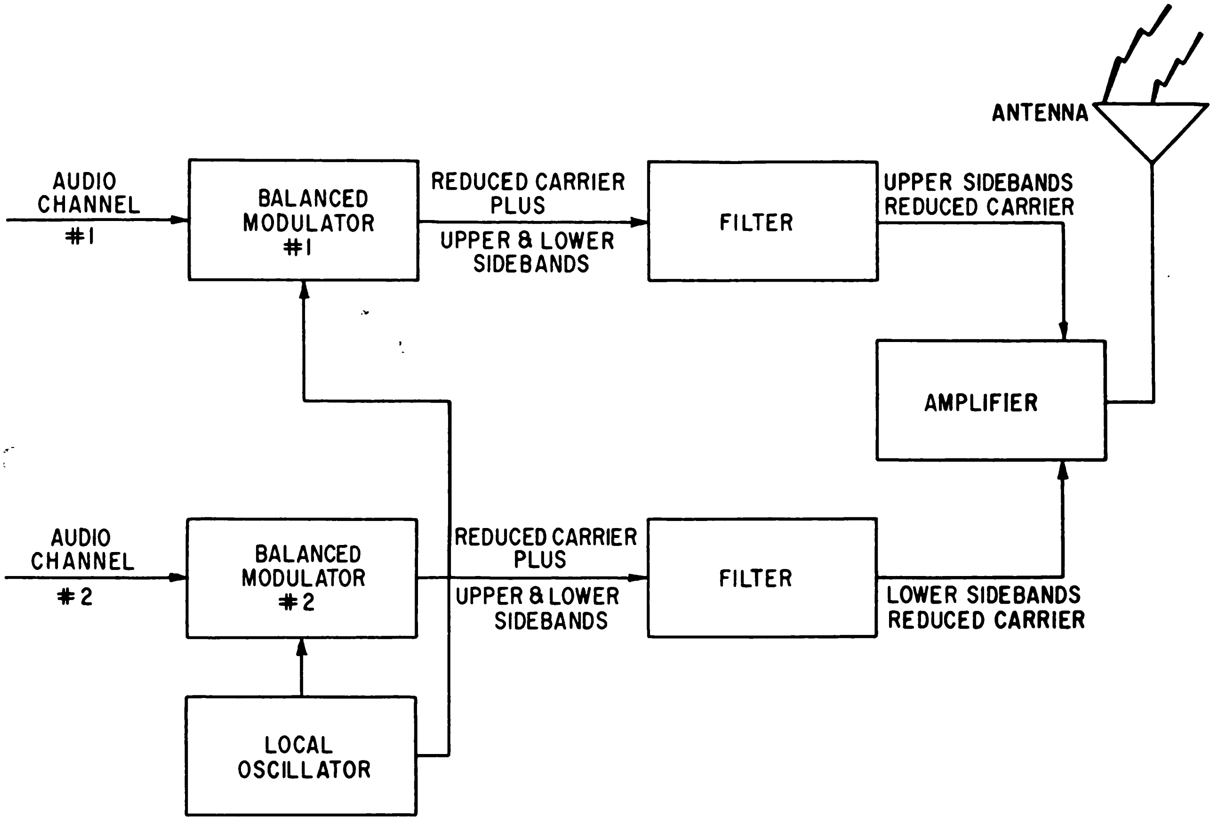


Figure 10-13.—Simplified block diagram of a two-channel SSB system.

one by the lower sideband and the other by the upper sideband. In order to do this, each message modulates the same carrier but in different modulators, as illustrated in figure 10-13. In a transmitter of this type the outputs of the two modulators usually contain the same carrier (reduced) as well as the different sidebands.

Filter circuits are provided for removing the upper sideband from one modulator output and the lower sideband from the other. The remaining sideband frequencies are then radiated from one antenna along with the reduced or suppressed carrier. Thus, each of the two sidebands conveys a separate message and may be used to provide a separate audio channel. Reception of the two channels requires only one receiver with suitable circuits for separating and demodulating each channel.

Phasing Method of Sideband Suppression

Phase cancellation can also be used to eliminate the unwanted sideband. One system uses two balanced modulators connected as shown in figure 10-11 (B). Balanced modulator No. 1 has the carrier (RF osc.) and modulating signals directly applied, while in balanced modulator No. 2 both signals are phase shifted 90 degrees. When the outputs of these two modulators (No. 1 and 2) are added, one phase is eliminated or canceled, and the other is reinforced.

SSB AMPLIFICATION

The most desirable characteristics in linear amplifiers are low distortion with maximum power gain. A linear amplifier is an amplifier having a certain power or voltage gain and an output waveform which exactly resembles the input waveform. Speech amplifiers or modulators are linear amplifiers. The speech amplifiers are linear audio voltage amplifiers while the modulators are linear audio power amplifiers. The only difference between those linear audio amplifiers and SSB amplifiers is the frequency involved—one is audiofrequency and the other radiofrequency. The same operating conditions are used, such as plate voltage, bias, load impedance, and so forth, in both cases. As has already been mentioned, nonlinearity produces distortion and distortion is highly objectionable in SSB because it can produce splattering into adjacent channels. This splattering is easily detected by sensitive receivers.

Class A operation of amplifiers gives a high degree of linearity and they are usually the ones referred to when speaking of linear amplification. But these have low power gain, and thus would result in a considerable power loss in high-power transmitters. Class AB operation is used in amplifiers when higher power gain is needed. High gain is required in SSB amplifiers because the modulated signal is usually generated at low levels (1 watt or less). To get this level to a kilowatt level requires high gain. To obtain high gain with a minimum number of stages and circuits requires the use of high gain tetrodes or pentodes, usually operated class AB. A minimum number of amplification stages is desired because each amplification stage produces distortion. However, negative feedback in RF circuits can be utilized to reduce distortion in the same manner as negative feedback in audio circuits. This is done by applying a sample of the output waveform to the amplifier's input to correct the distortion produced in the amplifier.

RECEIVING SSB

In the reception of SSB, the receiver must have rigid frequency stability because the reception is not as simple as with DSB signals. As previously mentioned, the receiver has the problem of furnishing an artificial carrier, since the SSB signal does not contain a carrier against which the sideband signals can be heterodyned in the receiver to demodulate the sideband and produce useful audio signals. As a rule, the artificial carrier is furnished by a highly stable beat frequency oscillator in the receiver.

It is necessary that the SSB transmitter have the same high degree of stability as the receiver. The maximum allowable drift between transmitter frequency and receiver frequency is about 50 cycles for good voice reception. Fifty cycles difference between transmitter and receiver will distort or change the pitch of the person's voice by 50 cycles. Although the intelligence will still be there, it does not constitute "good voice reception."

Figure 10-14 is a block diagram showing the essential functions of an SSB receiver.

The receiver employs necessary switching and tuning circuits to receive any signal within its frequency range, and to switch from upper sideband to lower sideband reception.

After the received signal is amplified, it is applied to mixer stages that lower the frequency. This is done in the same manner by which the frequency was raised in the transmitter. The carrier, necessary for heterodyning in the detector, is then inserted. Notice that the carrier generator is controlled by a frequency standard, as is the stabilized master oscillator (SMO), to maintain rigid frequency stability. After detection the original 2-kc. signal is fed to conventional audio amplifier stages.

Many of the units of an SSB receiver are identical with units of the SSB transmitter. The frequency standard, carrier generator, and SMO are identical. The double conversion mixer and amplifier unit of the receiver can be made identical to the double conversion mixer and amplifier unit of the transmitter. Because of this similarity, transceivers can be constructed with much of the circuitry used for both transmitting and receiving. This can be accomplished by merely adding switching arments to reverse the direction of signal flow.

SSB ADVANTAGES

In conventional DSB techniques of communication, there is a carrier, an upper sideband, and a lower sideband. The sidebands "beat" with the carrier to produce a single audio signal that carries the voice intelligence that is heard in the speaker or headset. If the upper or lower sideband is shifted in phase due to multipath sky wave propagation conditions, the signal heard is fuzzy, distorted, and in all probability quite loud. It is not uncommon to receive a report stating "loud but distorted." One sideband may experience a slight phase shift, thereby nearly canceling the other. The distortion produced causes the loss of intelligibility. Fading or slight phase shift of the carrier can also produce similar results. These problems reportedly do not exist in the suppressed-carrier type of SSB, particularly in the frequency range below 14 mc.

In conventional DSB technique of communication, with 100 percent modulation, approximately (neglecting losses) two-thirds of the transmitter's radiated power is in the carrier, and the remaining one-third is divided equally between the two sidebands. DSB and SSB

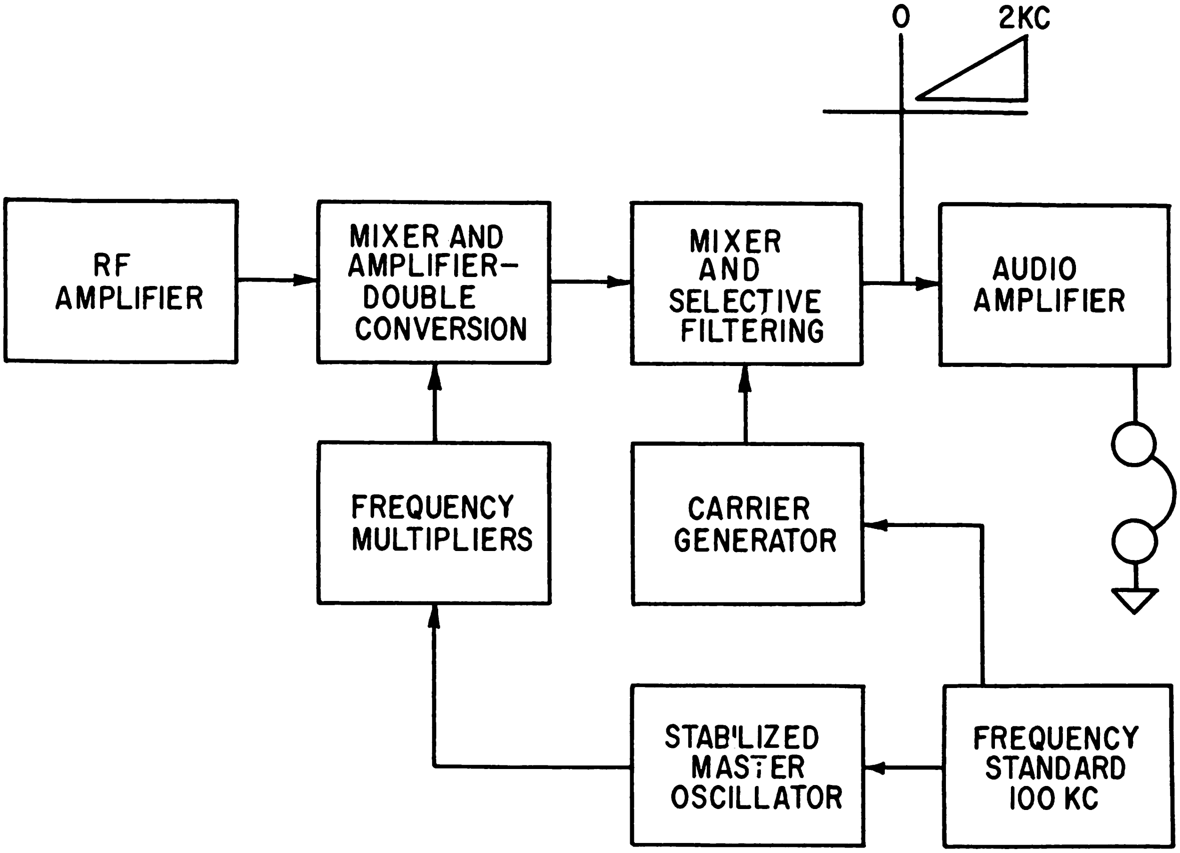

0
2KC
RF AMPLIFIER
MIXER AND AMPLIFIER–DOUBLE CONVERSION
MIXER AND SELECTIVE FILTERING
AUDIO AMPLIFIER
FREQUENCY MULTIPLIERS
CARRIER GENERATOR
STAB'LIZED MASTER OSCILLATOR
FREQUENCY STANDARD 100 KC

Figure 10-14.—Functional units of an SSB receiving system.

modulation relationship is illustrated in figure 10-15. Figure 10-15 (A) represents an unmodulated carrier of frequency f_1 with an average of 1,000 watts. Information can be transmitted by keying the carrier on and off, as in CW. The entire 1,000 watts of carrier power is used in transmitting information. In figure 10-15 (B) the same transmitter is shown being modulated 100 percent by a single sine-wave tone of frequency f_2. The useful information is contained only in the upper sideband frequency $(f_1 + f_2)$ and lower sideband frequency $(f_1 - f_2)$ that exist on either side of the carrier frequency.

Notice that the useful power is only 50 percent of that attained by the CW system in figure 10-15 (A). For practical voice modulation waveforms, this useful power may not exceed 30 percent of the total power. Figure 10-15 (C) represents a method of transmission known as a twin-channel single-sideband reduced-carrier system. (See fig. 10-13.) The carrier is not completely suppressed, but is reduced approximately 20 db in amplitude, serving as a pilot carrier. This pilot carrier is used as a reference for obtaining a reinserted carrier of correct frequency and phase in the receiver demodulator circuits, and for the AGC (automatic gain control) circuits. A brief discussion of this system has already been given. Figure 10-15 (D) represents a single-sideband suppressed-carrier system with complete suppression of the lower sideband and carrier. The only energy radiated by this method is modulation energy.

In this method a higher degree of oscillator frequency stability is required for both the transmitter and receiver circuits than for the method using the pilot carrier. Thus, with the suppressed-carrier SSB system, all of the power goes into the single sideband which carries the useful voice intelligence.

Since there are good and poor suppressed-carrier SSB signals as well as good and bad DSB signals, it would not be fair to compare a good DSB signal with a bad suppressed-carrier SSB signal, or vice versa.

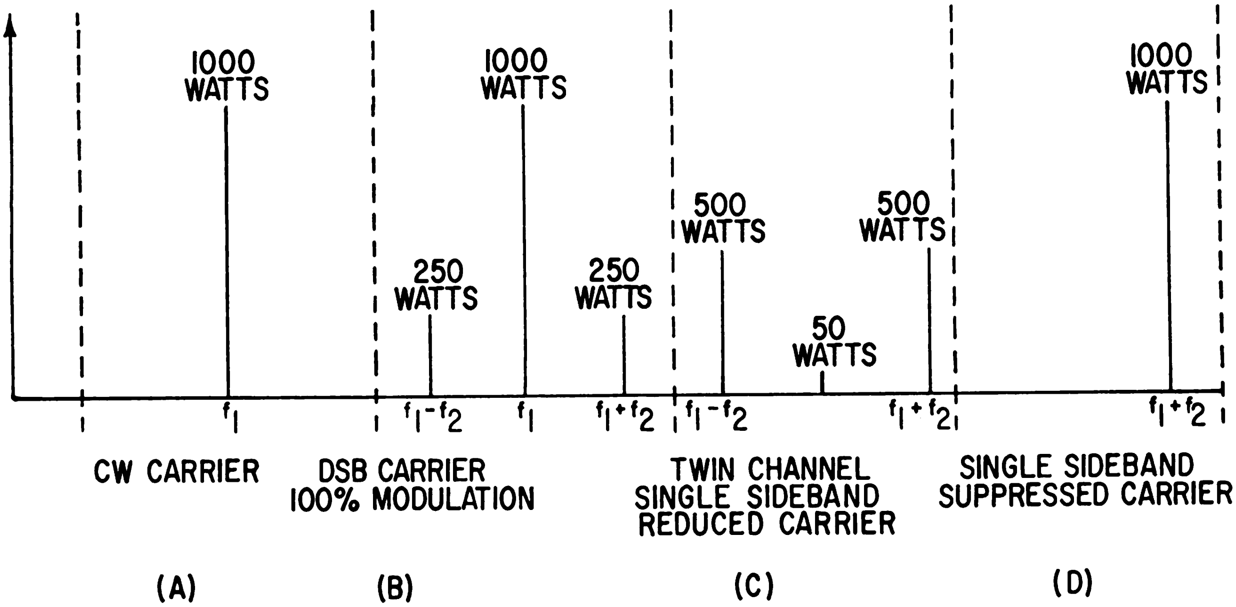


Figure 10-15.—DSB and SSB modulation power relationship.

In any system of comparison, it is essential that conditions under which the comparison is made be clearly defined. Figure 10-16 illustrates one method of comparison of suppressed-carrier SSB and DSB. The comparisons made here assume coherent detection of sidebands in DSB and also ignore the possible differences that can occur under various propagation and interference conditions. Figure 10-16 compares "talking power" between DSB and SSB. It illustrates that as bandwidth is decreased an SSB transmitter requires progressively less power output to obtain the same "talk power" as a DSB transmitter. In this illustration the output of the DSB transmitter is 1,000 watts.

Figure 10-16 (A) illustrates that a 1,000-watt DSB transmitter will "talk" just as loud as a 1,000-watt SSB transmitter if both are received on a wide-band (6 kc.) receiver. Figure 10-16 (B) illustrates that under optimum conditions—that is, DSB received at bandwidth of 6 kc. and SSB received at bandwidth of 3 kc.—the talking power of a 500-watt suppressed carrier SSB transmitter is equal to a 1,000-watt DSB transmitter. Figure 10-16 (C) illustrates that if both DSB and suppressed-carrier SSB are received on a narrow bandwidth receiver, then the talking power of the 250-watt SSB transmitter is equal to a 1,000-watt DSB transmitter. It has generally been accepted that, under normal operating conditions with moderate signal-to-noise ratios, the improvement in gain of SSB is between 6 and 9 db over an equivalent DSB transmitter. The suppressed-carrier SSB transmitter provides 6 db gain and the remaining db gain is derived from the narrow-band single-sideband receiver's selectivity. Propagation conditions determine the relative advantages of suppressed-carrier SSB over DSB. As the interference and/or selective fading becomes worse, SSB will indicate a greater advantage over DSB.

Another advantage of SSB operation is that interference is reduced. In normal voice DSB communication, the carrier of the transmitter remains on the air until the transmitter is turned off. If a second transmitter transmits while the carrier of the first station is on the air, distortion results. Squeals and howls are caused by the heterodyning of two or more signals being transmitted at the same time. With SSB, as soon as the individual stops speaking into the microphone, "talk power" in the sideband leaves the air even if the transmitter is still on, and the receiver is automatically deenergized.

When two SSB stations transmit at the same time, a receiving station can receive through the interfering station in the same way that an individual is able to listen to more than one conversation at the same time.

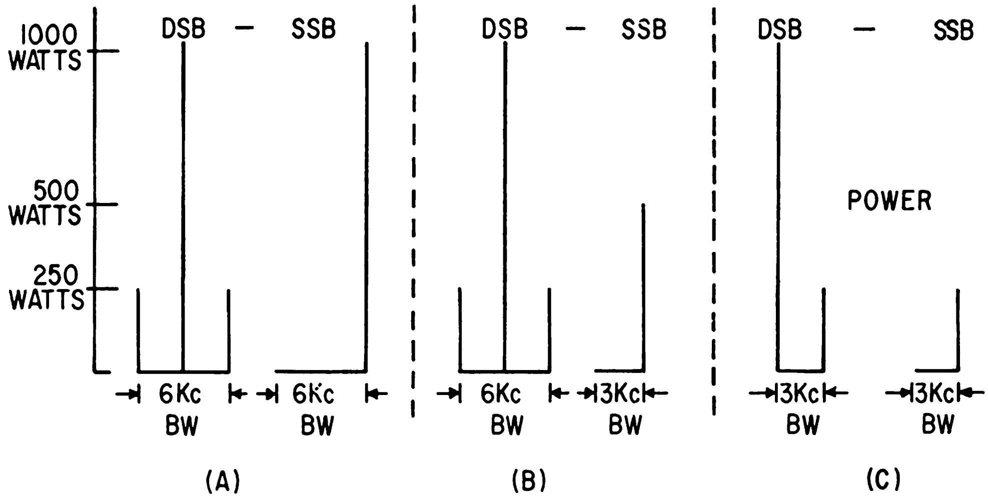


Figure 10-16.—DSB and SSB power comparison.

Tape Recorders

Tape recorders are now replacing wire recorders throughout the Navy. Some advantages of tape over wire are improved frequency response, better signal-to-noise ratios, less distortion, and ease of operation.

Recorders are presently being used in many different applications. For example, they are utilized in control towers, experimental projects, and some aircraft. All tape recorders employ the same basic principles of operation; that is, a tape having some permeable material on its surface is caused to pass over an electromagnet that is energized by whatever intelligence is to be recorded.

The material that follows will present the theory of operation of tape recorders in general. A recorder that is presently being used in naval aviation is also discussed.

BASIC PRINCIPLES OF MAGNETIC TAPE RECORDING AND REPRODUCING

If a material capable of being magnetized is placed in the proximity of a magnetic field, the molecules of the material will be oriented according to the direction of the field. Any of several methods can be used to produce the magnetic field, but of most interest in magnetic recording is that field produced when a current flows through a coil of wire. The current may be derived from a transducer—for example, a microphone converting audio sound waves to electric current.

Magnetic recording tape consists of finely divided iron oxide particles deposited upon a plastic backing. This tape is moved through a magnetic field in which the magnetizing force is alternating, and the iron oxide particles are alined according to the instantaneous direction and magnitude of the field. This is illustrated in figure 10-17.

The magnetic field is produced in the gap of a recording head, over which the recording tape passes. The recording head is a split ring electromagnet as may be seen in figure 10-18. It consists of an incomplete ring of highly permeable material inserted in a coil of wire. One discontinuity in the ring forms the gap, and the ring is the electromagnet.

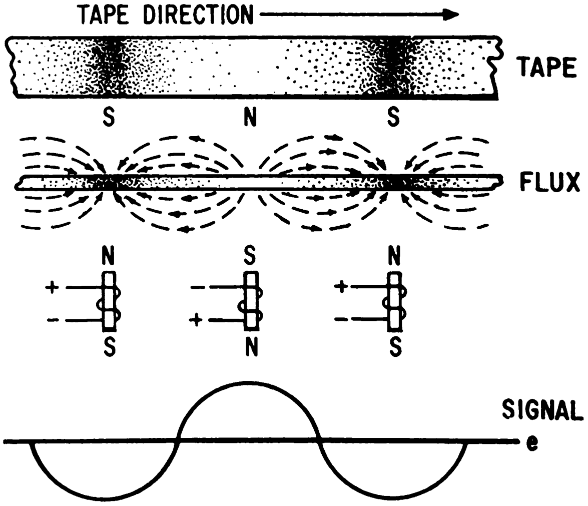


Figure 10-17.—Tape magnetization principle.

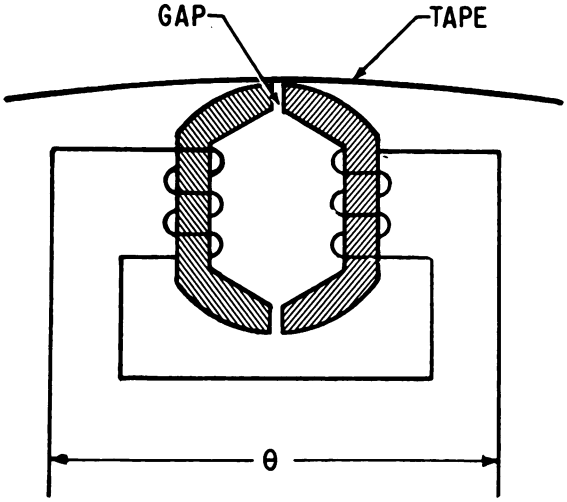


Figure 10-18.—Recording head.

Consider the equation

$$H = B/\mu$$

where

H is the magnetizing force, proportional to the current through the coil.

B is the magnetic flux density.

μ is the permeability of the core material.

In a series magnetic circuit, assuming a constant cross-sectional area, the flux density is the same in all parts of the circuit in the same manner as the current is the same in all parts of a series electrical circuit. Referring to the above equation, it can be seen that in the case of a core material with a μ of 50,000 and an air gap with a μ of 1, the magnetizing force across the gap will be 50,000 times that in the core.

The magnetization curve of the iron oxide utilized as the recording medium is similar to that shown as the heavy lines in figure 10-19. At points near the origin, the curve is extremely nonlinear, and the signal recorded on the tape would not be directly proportional to the signal applied to the head. This would result in a high degree of distortion upon reproduction, due to hysteresis effects. This distortion is greatly reduced by the application of a high-frequency constant amplitude bias signal which is mixed with the signal being recorded. The frequency of this bias is generally selected to be five times the upper frequency limit of the recorder to prevent beating between the bias and harmonics of the recorded signal.

While the tape is in the recording gap, the bias causes the magnetization characteristics of the iron oxide to follow the dashed line loops, known as the minor hysteresis loops. (See fig. 10-19.) As the tape leaves the gap, the influence of the magnetic field created by the bias is reduced to zero, and the tape assumes a permanent magnetization, known as remanent induction, determined by the gap flux.

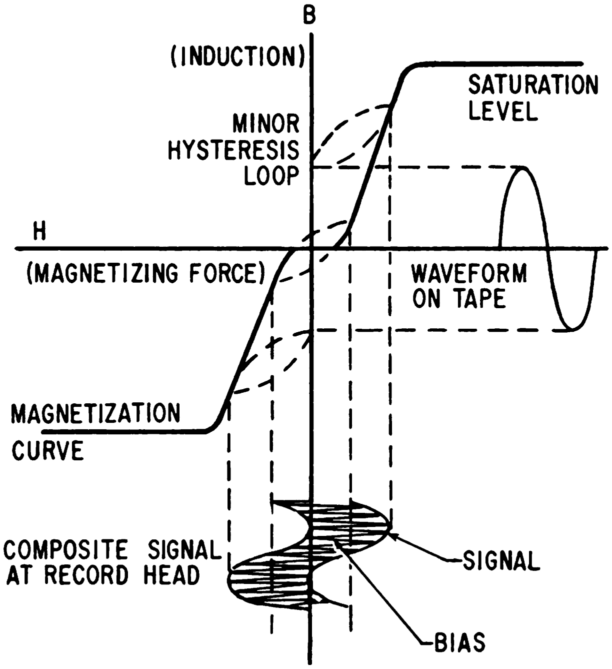


Figure 10-19.—Magnetization curve of the tape.

After the recording process, there exists on the tape a flux pattern which is proportional in magnitude and direction to the signal recorded on it. If the tape is then moved past the gap of a reproduce (or playback) head—which is similar in construction to the record head—the magnetic flux of the moving tape will induce a voltage in the coil of the reproduce head. This induced voltage is proportional to the number of turns of wire on the head and the rate of change of flux.

It is desirable that the gap in the reproduce head be as small as practical, so that the gap will intercept less than one wavelength of the signal on the tape at the highest frequency to be reproduced. However, as the gap is made smaller, the induced voltage decreases; so there is a practical limit in decreasing the gap and still maintaining an adequate signal-to-noise ratio.

The voltage across the coil increases directly as the tape's velocity increases and as the frequency increases. If the tape velocity and gap width are assumed to be constant, the output voltage from the head is directly proportional to the frequency, as long as the wavelength on the tape is large compared to the gap width. This results in an output-versus-frequency characteristic resembling curve A of figure 10-20.

The voltage does not continue to rise indefinitely. As electrical losses in the core material increase, and as the wavelength on the tape approaches the same dimensions as the reproduce head gap, the actual output resembles curve B of figure 10-20.

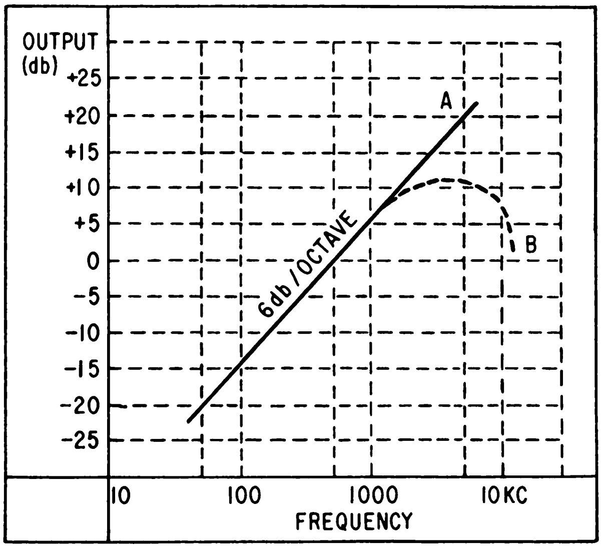


Figure 10-20.—Output-versus-frequency curve.

Mechanical Operation

The tape transport mechanism illustrated in figure 10-21 consists basically of two systems—a tape drive system and a tape tension system. The tape drive system moves the tape at a constant speed from the tape supply reel, across the heads, to the tape takeup reel. The tape tension system insures that the tape is under proper tension at all times and that its axis is always in the same position relative to the heads.

1. TAPE DRIVE SYSTEM. A typical tape drive system consists of a constant-speed, d-c, governor-controlled motor, a capstan assembly mounted on a flywheel, and a capstan idler and solenoid. The drive motor is mechanically coupled to the flywheel through a nylon belt, and drives it—and consequently the capstan—at a constant speed. The tape is threaded between the capstan shaft and the capstan idler. The drive motor will run whenever the POWER switch is in the ON position, but there will be no movement of the tape until the RECORD-STANDBY switch is placed in the RECORD position, at which time the capstan solenoid is energized and the capstan idler presses the tape against the rotating capstan. Tape is supplied to the drive system by the tape supply reel, and is taken up by the takeup reel.

2. TAPE TENSION SYSTEM. The tape tension system consists of the tape supply assembly and the takeup assembly. A turntable with a brake band riding on the turntable drum makes up the tape supply assembly. As the capstan moves the tape at a constant speed across the heads, the rate of rotation of the tape supply turntable will vary as the effective diameter of the tape on the reel hub changes—a low speed when the reel is full and a progressively higher speed as the reel empties. The brake band shown in figure 10-22 serves two functions. It provides optimum tape tension as the rate of rotation of the reel varies, and it also provides a braking force to stop the tape supply turntable when the recorder is changed from RECORD to the STANDBY mode of operation.

The tape takeup assembly consists of a d-c torquemotor, the takeup turntable, and takeup reel. The rate of rotation of the takeup turntable and reel must also vary in the same manner as the tape supply reel. The torquemotor is sensitive to load, and as the amount of tape on the reel increases, the speed of rotation will decrease. The takeup motor operates when the RECORD-STANDBY switch is in the RECORD position.

When the recorder is changed from the RECORD to the STANDBY mode of operation, the capstan idler moves away from the capstan, and the takeup motor stops. In the absence of any other force, the inertia of the tape supply reel would cause the reel to continue rotating, thus supplying tape that would not be taken up by the takeup reel. This would result in a large tape loop being thrown between the two reels. This is prevented by the action of the brake band on the supply turntable drum, which stops the supply reel and permits no tape to be supplied after the switch is placed in the STANDBY position. If tape breakage should occur, or if tape supply is exhausted, the takeup motor will stop automatically.

The tape guide assembly is a spring-pivoted assembly which guides the tape into the heads;

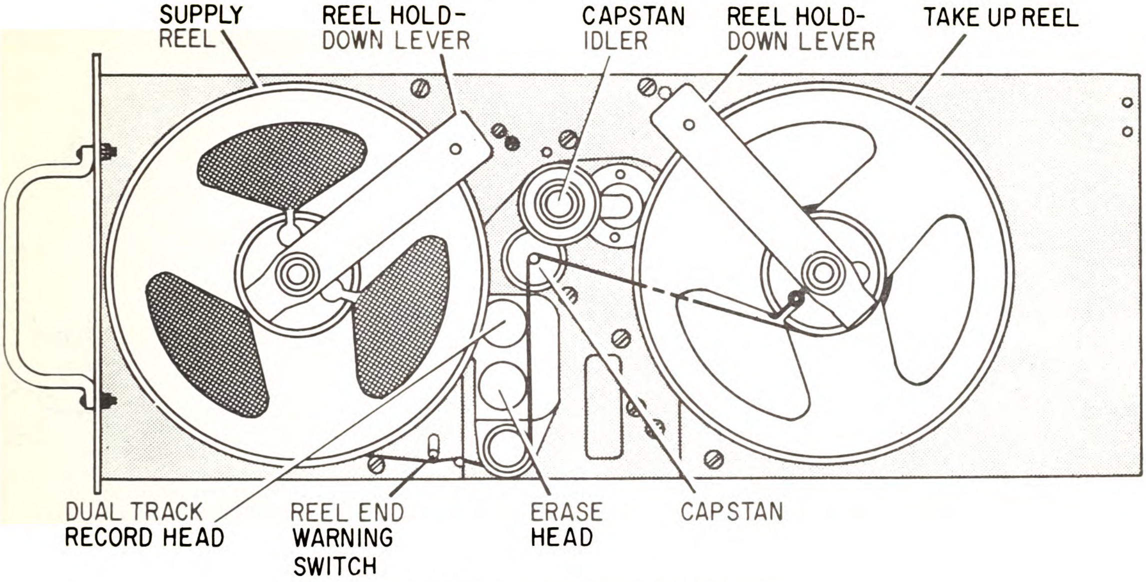


Figure 10-21.—Tape transport components.

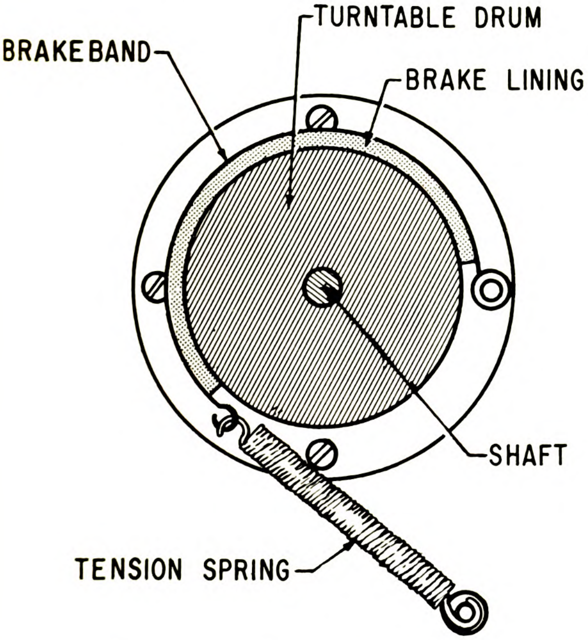


Figure 10-22.—Brake components.

it also causes the tape to pass through the heads in the proper position.

The reel-end warning switch mechanism consists of a pivot-mounted arm located between the tape supply reel and the tape guide assembly. As the amount of tape remaining on the supply reel diminishes, the angle of feed with respect to the warning switch mechanism increases. Approximately five minutes before the end of the reel, the angle is such that the switch is actuated, lighting a lamp on the remote control unit.

Typical Tape Recorder

The circuitry of a magnetic tape recorder may be best described by referring to the block diagram in figure 10-23.

The control circuit contains the relays for operating the recorder and the capstan solenoid. It also contains the power distribution controls for the recorder. In order to allow the recorder to operate at below freezing temperature, thermostatically controlled heaters are incorporated which operate if the unit cools below 32° F.

The power supply consists of a vacuum tube rectifier connected for full-wave rectification, a filter and decoupling network, and a voltage regulator tube.

The bias and erase oscillator supplies high-frequency bias to the record head, and erase current to the erase head. The principle of erasing consists of passing the recorded tape through a decaying alternating magnetic field. The bias and erase oscillator is located in a shielded enclosure. It may be a conventional Colpitts push-pull triode oscillator operating at approximately 100 kc. (The exact frequency is not important.)

Two identical signal or "record" amplifiers, one for each channel, are located on a terminal board of the recorder chassis. Each is a dual

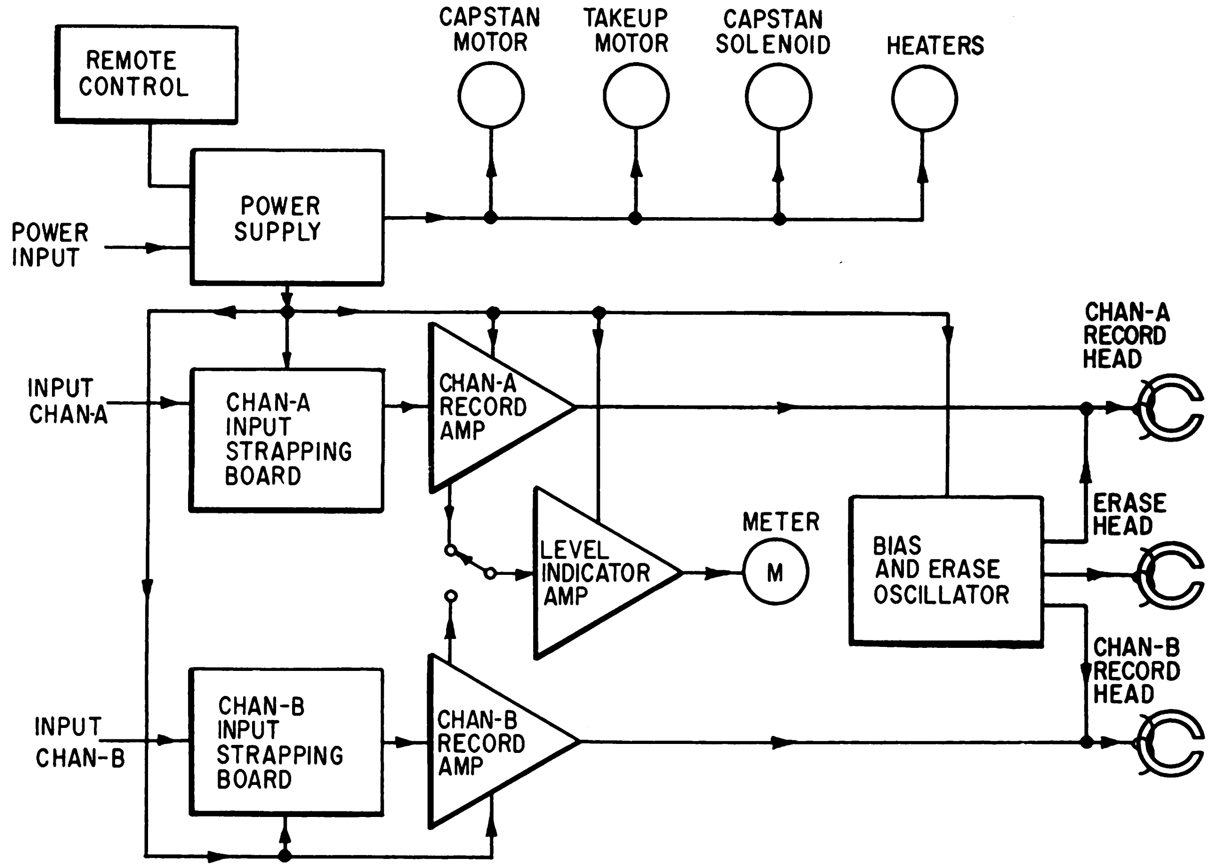


Figure 10-23.—Block diagram of a typical magnetic tape recorder.

stage triode amplifier with transformer input. The input of each amplifier may be arranged to accommodate a 500-ohm balanced line input or a carbon microphone. When arranged for the carbon microphone input, 6 volts d.c. is supplied from the 28-volt d-c source through voltage dropping resistors. Potentiometers, one for each channel, are used to adjust the record level of the amplifiers.

The output of the first stage of each amplifier, in addition to driving the second stage, is fed to the meter amplifier so that the signal or record level may be checked before or during recording. The output of the second stage of each amplifier is mixed with the high-frequency bias and supplied to the respective record head.

The meter amplifier enables the recording level for either amplifier to be checked before or during the recording process. This circuit consists of the CHANNEL SELECTOR switch, which connects the desired channel to the amplifier, and a cathode follower whose output is fed to a rectifier type meter.

The AN/UHN-6 Tape Recorder

The UHN-6 magnetic tape recorder (fig. 10-24) operates very much like the typical recorder just described. It is installed in some P5M aircraft for recording audio, sonobuoy, and ECM reception. The following discussion will apply to that particular installation. However, this recorder may be installed in many types of aircraft and a similar operational procedure will apply in most installations.

This recorder records audio from two sources simultaneously on separate channels (A and B). On channel A, audio is recorded from the sonobuoy receiver and the ASW interphone system. According to the selection for channel B, audio is recorded from the radio operator's ICS control or the countermeasures receiver.

The units of the tape recorder set consist of the recorder RD-28/UN and a remote control

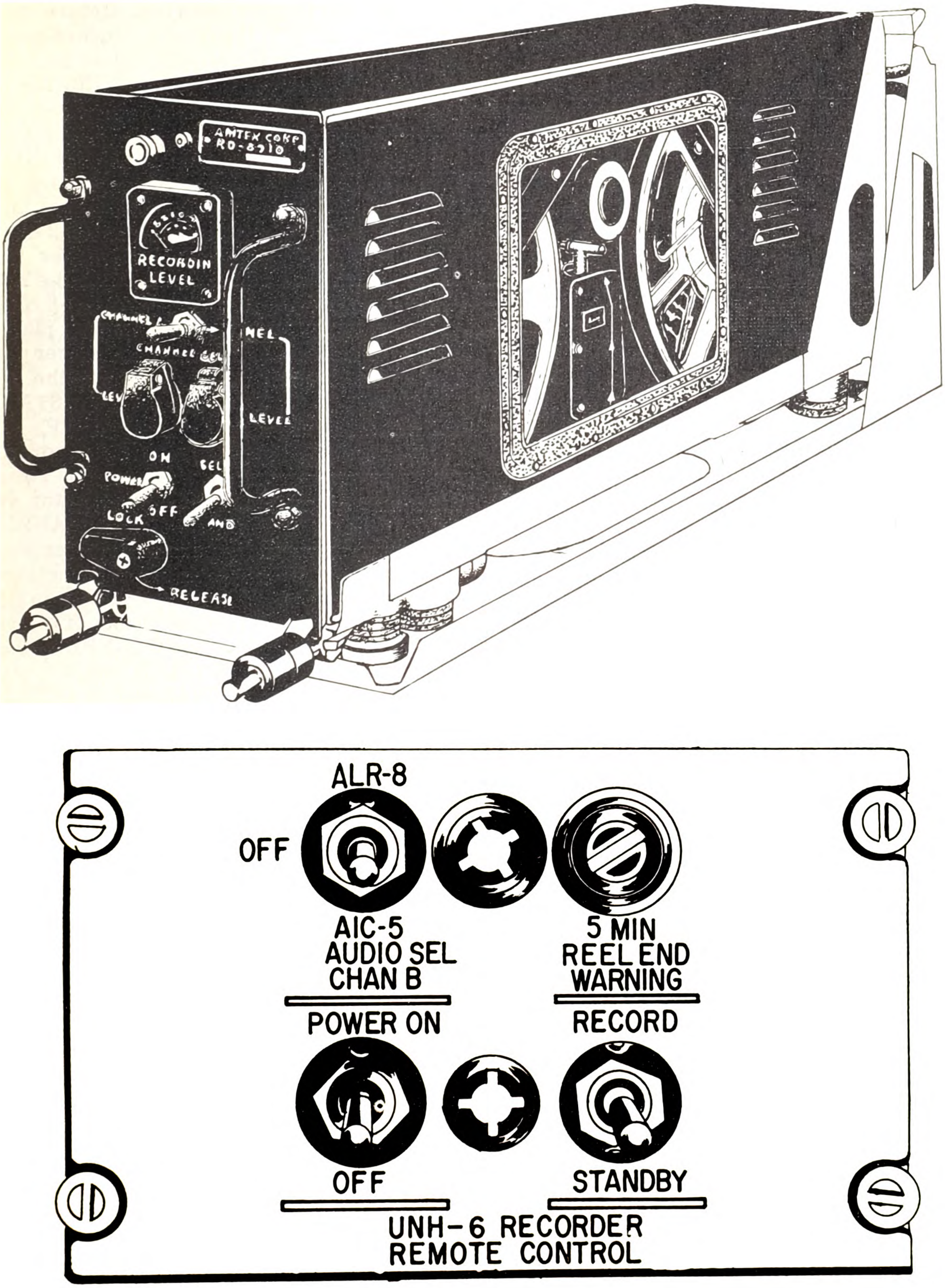


Figure 10-24.—Magnetic tape recorder and control.

panel accessible to the sonobuoy and ECM operators. (See fig. 10-24.) Both the recorder and the remote control contain a POWER switch, RECORD-STANDBY switch and a 5 MIN REEL-END WARNING LIGHT. Placing the equipment in operation is accomplished from either unit. However, the source of audio to be recorded on channel B can only be selected from the remote control.

A 7-inch diameter reel containing 1,800 feet of 1-mil thickness and 1/4-inch wide polyester base tape provides 48 minutes of actual recording. Time markings beneath the supply and takeup reels indicate the remaining and elapsed time of recording. When the tape is five minutes from ending, a switch, sensitive to the angle of the recording tape as it leaves the supply reel, will energize a warning light on the recorder and the remote control panel. If a tape breakage occurs or the tape supply is exhausted, the takeup motor will stop.

Power for the recorder set in the P5M aircraft is obtained from the 115/200-volt, 400-cycle, a-c bus through a 2-ampere fuse, and from the 28-volt d-c bus through a 10-ampere circuit breaker marked RECORDER sonobuoy. Both fuse and circuit breaker are on the navigator's distribution panel.

The procedure to follow when installing recording tape is as follows: Release the LOCK-RELEASE lever, on the recorder control panel (fig. 10-24), and slide the recorder chassis out of the cover until it locks in the fully extended position. With the two spring-loaded reel holddown levers raised (fig. 10-24), place a full reel of tape on the supply turntable so the reel will rotate counterclockwise as the tape is pulled from it. Engage the reel with the turntable keys and lower the holddown levers to secure the reel. Similarly mount an empty reel on the takeup turntable. Thread the tape as shown in figure 10-21, making sure that the dull side of the tape contacts the erase and record heads. To anchor the tape to the takeup reel, make a loop approximately one inch long at the tape end and insert it into the aperture in the hub. Pull sufficient tape from the supply reel so that no tension will be encountered and rotate the takeup reel three or four turns counterclockwise. Return the recorder chassis to the original locked position.

The following procedure should be followed when operating the recorder. With the navigator's a-c and d-c buses energized, check the 2-ampere fuse and close the 10-ampere circuit breaker. These are marked RECORDER sonobuoy on the navigator's distribution panel. With the RECORD-STANDBY switches on both control panels in STANDBY (fig. 10-24), close the POWER-ON switch from either panel. Place the audio selector switch on the remote control panel for channel B to ALR-8 or AIC-5. After a short warmup period, place the RECORD-STANDBY switch from either control panel to RECORD. To deenergize the equipment, return the RECORD switch to STANDBY and turn the POWER switches to OFF.

The recording level of the set is adjusted in the following manner: With the tape recorder in operation, place the channel selector switch on the recorder control panel to CHANNEL A. Raise the spring-loaded access cover and use a screwdriver to set the LEVEL potentiometer for CHANNEL A so that the meter indicates zero v-u (top scale) on the peaks of the signal to be recorded. Place the CHANNEL SELECTOR switch on CHANNEL B and repeat the procedure, using the CHANNEL B LEVEL potentiometer to set the record level.

The record level indicator is calibrated so that a recording is accomplished at optimum level when the meter indicates zero v-u on the most intense peaks of signals whose ratio of peak to average intensity is approximately equal to that given when a person speaks in a normal tone of voice. As the meter can indicate only average intensity of a signal, some compensation may be desirable if a signal with a peak to average amplitude ratio is considerably higher than that encountered in ordinary speech. A signal composed of widely spaced, high amplitude pulses of short duration would fall into this category. If signals of this general type are to be recorded it would be advisable to make experimental recordings at different levels such as: -3, -6, -10 v-u until the desired results are obtained when reproducing the information.

Television

Because it is anticipated that television (TV) will become widely used in naval aviation, it is necessary that the AT acquire a working knowledge of the basic principles. Only the basic principles will be presented, as television theory is quite lengthy. Much of the theory is covered in *Basic Electricity*, NavPers 10086, and *Basic Electronics*, NavPers 10087. Television utilizes common electronic parts such as resistors, capacitors, coils, vacuum tubes, and so forth. You should already be familiar with all of these. There are, of course, special forms and applications of these parts that comprise special circuits. To learn the theory of TV you must study each circuit individually, then tie them all together to complete the system.

This discussion includes the television camera, the composite signal that is transmitted, and the receiving system. Certain abbreviations and terms will be used and these will be explained now.

"Sync" is short for synchronizing, and will be used when referring to the "sync pulses" that synchronize the actions of the transmitter and receiver. "Mosaic" is a term that describes the picture pickup plate in the TV camera. It is coated with a light-sensitive substance that acts like a large number of small, individual globules that emit electrons when struck with light. "Video" covers a large band of frequencies, from audio to several megacycles. However, in the discussion of the transmitter the term video will refer only to that portion of the transmitted signal that carries the picture intelligence and the blanking and sync pulses. Sound will be treated separately. In discussing the composite signal the term video will refer only to the picture intelligence, while sound, sync, and blanking pulses will be treated separately. The reason for this treatment of the signal will be apparent as each section is studied.

A SIMPLIFIED TELEVISION SYSTEM

Functional Block Diagram of a Television System

A simplified block diagram of a television system is shown in figure 10-25. The diagram contains three main divisions. The one at the top represents the video transmitter. The centrally located division represents the audio transmitter, and the lower division represents the television receiver.

In the video transmitter, the camera tube provides a means of converting light rays from the object on which the camera is focused into electrical impulses. Light from the object is focused on the mosaic in the camera tube by means of the lens system. As the electron beam moves across the mosaic, traversing it line by line (scanning it), minute electrical impulses, corresponding to the light and dark portions of the image, are picked off and sent to the video amplifier.

The video amplifier, which is capable of amplifying a wide range of frequencies, amplifies the very weak electrical impulses and passes them to the control amplifier.

In the control amplifier, sync signals from the sync generator are added. These sync signals are used to trigger the sweep of the electron beam in the receiver picture tube so that it will be in step with the sweep of the electron beam in the camera tube.

In the amplitude modulator, the carrier wave is modulated by the video sync and blanking signals. Blanking signals blank out the electron beam during the time that the sync signals are applied. The composite (total) signal is then amplified and radiated by means of a special antenna array. Remember that every part of the signal is amplitude modulated except the sound.

Simultaneously with the actions that are taking place in the video transmitter, other actions are taking place in the FM sound transmitter that is associated with the AM video transmitter.

The sound is picked up by the microphone, amplified by the audio amplifier, and fed to the frequency modulator. Here the carrier is varied in frequency according to the applied sound energy. The signal is then amplified and radiated by means of a special antenna.

At the television receiver, the video, audio, blanking, and sync signals are picked up by the antenna. The signals are amplified in the RF section. In some sets (employing split sound), the sound is picked off at the output of the RF section and fed to a separate sound IF amplifier. The sound signal is detected by an FM detector; it is then amplified and fed to the speaker. In other sets (employing intercarrier sound), the composite signal (video, sync, and audio) is fed through a common IF system. The sound is then fed to the sound amplifier, the sync signals are fed to the sweep circuits, and the video and blanking signals are fed to the video amplifier. The video amplifier amplifies the video signals and feeds them to the picture tube. In many receivers the sync signals are fed from the output of the video amplifier to the sync and sweep circuits.

As may be seen in figure 10-25, the sync generator at the transmitter keeps the whole video system in step as far as the sweeping of the electron beam at the transmitter and the receiver is concerned. Also, it may be seen

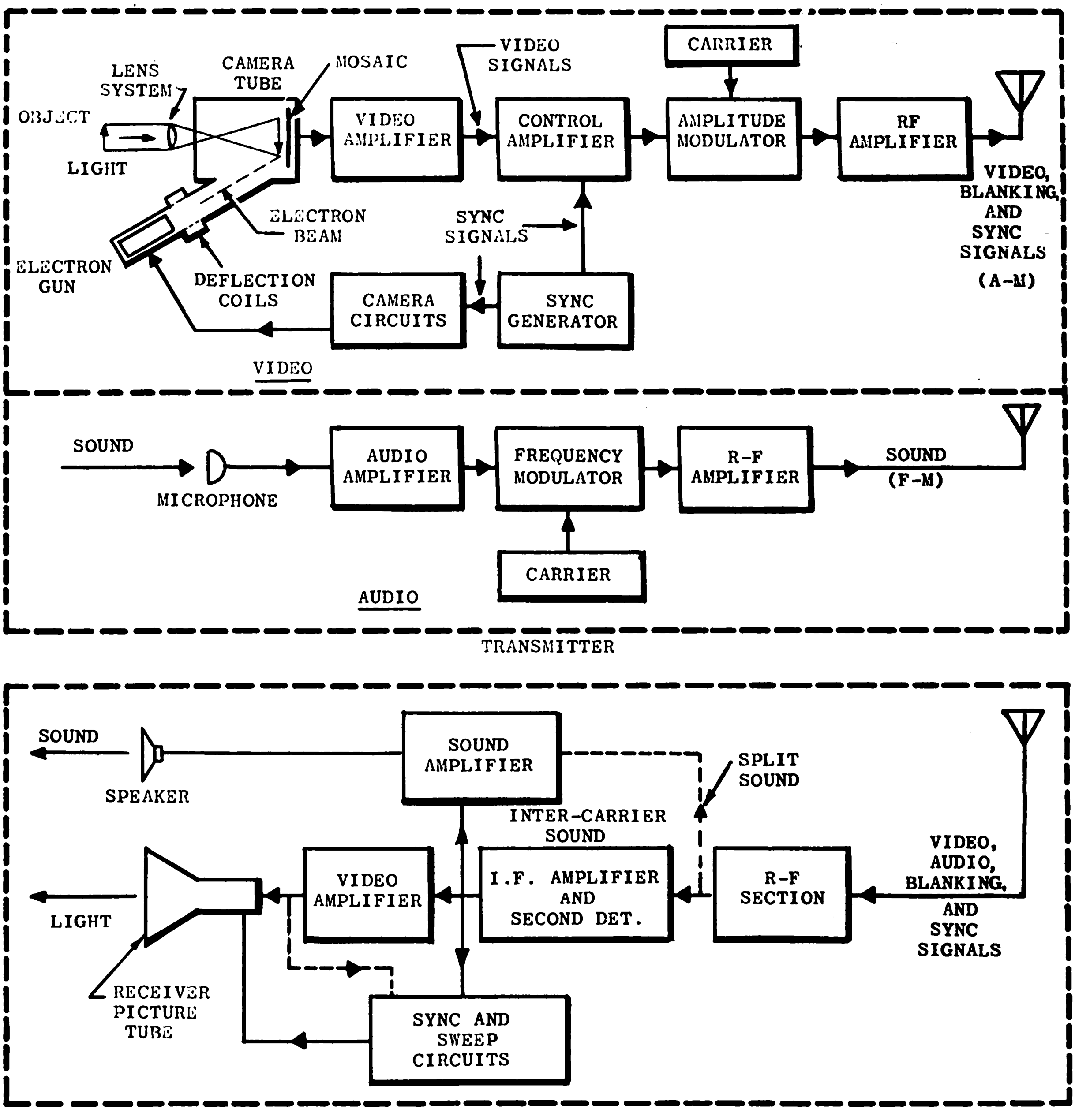


Figure 10-25.—Simplified block diagram of a television system.

that the sound system is separate from the video system. The necessary power supplies, monitoring devices, and control circuits have been omitted in the interest of simplicity.

Picture Elements

If a photograph, such as a contact print, is examined with a magnifying glass, it will appear to have a grainy structure. That is, it is composed of thousands of individual particles having various shadings between black and white. Each of these particles may be considered an element of the picture. The eye sums up, or integrates, the elements and the viewer sees the complete picture.

A photograph having many elements has a large amount of detail. A photograph having fewer elements has less detail. However, if a picture having a great amount of detail is sufficiently enlarged it will appear to have a grainy texture and to lack detail.

If a picture printed from a photoengraving (for example, a halftone picture in a newspaper) is observed carefully it will be seen to be composed of a large number of black dots of various diameters. The small, widely spaced dots make up the whiter portions of the picture and the large, closely spaced dots make up the darker portions of the picture. As in the case of the photograph, these dots (discrete parts) are the elements that make up the picture.

In forming a television picture, or image, much the same situation is encountered. There is, however, one very important difference. In the photograph or the picture made from the photoengraving, all of the elements of the figure are viewed simultaneously. In the television picture, the elements are presented one after the other in quick succession so that the observer appears to see the picture as a whole. The method of presenting the elements in quick succession is described later. First, a description of the operating principles (how the electrical equivalents of the elements are produced) of some common types of television camera tubes will be given.

Camera Tubes

The structure of the Iconoscope manufactured by RCA, is shown in simplified form in figure 10-26. The image of the object is formed on the mosaic, which is composed of a large number of globules of a light-sensitive compound spread over the surface of a mica plate.

The back of the mica plate has a metal coating. Light shining on this compound causes each globule to emit electrons. Such electrons are called photoelectrons, and are released from the globule to the collector ring. For each electron released one is drawn up through R to the metal plate to replace the change on the globule. These globules are insulated from each other and therefore each globule may acquire a charge independently of the others. Because each globule is separated from the metal coating by the mica dielectric, thousands of tiny capacitors are formed, all having a common plate. Where the image is bright, many electrons are released from the globules, and the globules acquire a relatively large positive charge. Where the image is dark, few electrons are released from the globules, and they acquire a relatively small positive charge. In other words, the amount of charge acquired by a particular globule varies in proportion to the amount of light shining on that globule.

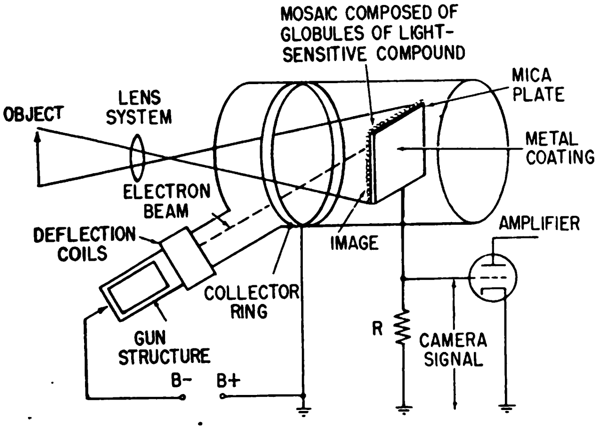


Figure 10-26.—Structure of Iconoscope.

If each tiny globule is thought of as being a picture element, the similarity to a newspaper halftone will be apparent. However, it is more meaningful at this point to consider the charge on each globule as being equivalent to a picture element. If the plate contains few (but large) globules, there will be a lack of detail. If it contains many small globules, there will be good detail. It is assumed that in each case the electron beam used for scanning is very small in cross section—that is, of the order of the diameter of the globule. An electron beam of large cross section would cover several globules, and the finer details would be lost just the same as if the globules were large.

The method by which the charges stored on the globules are translated into electrical impulses is treated under scanning.

The structure of the Image Orthicon, also manufactured by RCA, is shown in simplified form in figure 10-27. The image of the object is formed on the photocathode by the lens system, as in the case of the Iconoscope. This system differs from the Iconoscope, however, in that the photoelectrons are given off from the side of the plate opposite to the one on which the image is formed. The number of photoelectrons emitted from each unit area of the photocathode is proportional to the intensity of the light falling on that unit area. Thus, in effect, an electron image is formed by the photoelectrons leaving the photocathode.

The high positive potential on the wall coating draws this photoelectron image to the two-sided target where secondary electrons, proportional to the number of photoelectrons

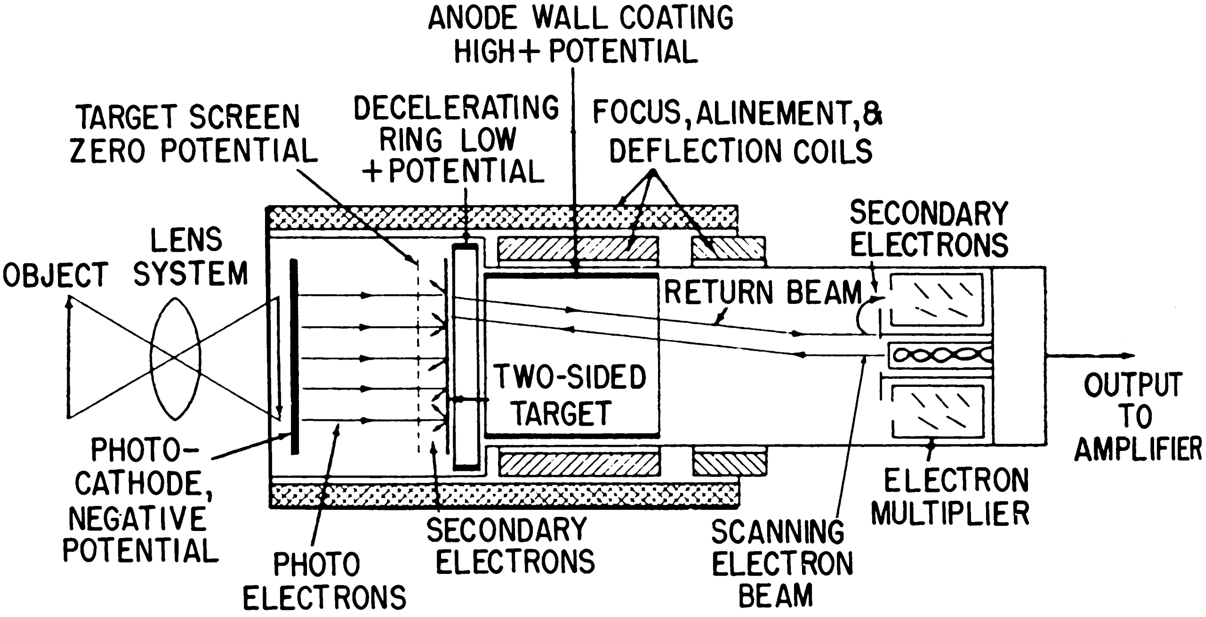


Figure 10-27.—Structure of Image Orthicon.

arriving per unit area, are given off. These secondary electrons are picked up by the fine screen placed in front of the target. Each unit area of the target is charged to an amount proportional to the number of secondary electrons released.

The target is made of special material that has very low resistance in the direction of the axis of the tube, but has high resistance laterally across the target. Thus, the positive charge developed on each unit area of the target by the emission of secondary electrons is effectively isolated from the adjacent charges.

The electron beam scans (moves across) the back of the target plate. The velocity of the impinging electrons is reduced by the low potential on the decelerating ring. The number of electrons in the impinging beam that are returned from a unit area of the target via the return beam depends on the positive charge on that unit area. A high positive charge requires more electrons from the impinging beam to become neutralized, and therefore fewer electrons are returned to the electron multiplier. A lower positive charge subtracts fewer electrons from the impinging beam and more electrons are returned to the electron multiplier. Thus, when the electron beam is impinging on an element of the target, the number of electrons in the return beam is inversely proportional to the positive charge on the target element.

Every detail of this tube is designed to give the greatest signal output for the least amount of light on the photocathode, and therefore it has a relatively high sensitivity.

Before the light and dark portions (elements) of the image can be translated into equivalent electrical impulses, the image must be scanned.

Scanning

As previously mentioned, the television image (or the electrical impulses that are the equivalent of the image) is transmitted element by element in quick succession. In the present state of the art, any other method of transmission would be too complex and expensive. Fortunately, it is possible to transmit and reconstruct the image in this manner and still maintain good picture quality provided the number of picture elements transmitted and reproduced remains large.

In order to transmit the image impulses element by element, it is necessary to employ a system of scanning; that is, the image is swept by an electron beam in a systematic manner so that during a given period of time all parts of the image are covered, or swept, by the electron beam. Likewise, in the receiver, where the image is reconstructed, a similar system of scanning is employed. The receiver electron beam is kept in synchronism with the transmitter camera by means of sync pulses.

A crude example will illustrate one type of scanning technique. Assume that a person has a flashlight that can produce a very narrow beam of light and that he wishes to view a picture on the wall in a darkened room. Obviously, he must view a portion of the picture at a time. If he could manipulate the light very fast, he might view the picture in the same manner that a picture is produced in television. He could start at the upper left-hand corner of the picture and move the beam rapidly across the picture. The light could then be cut off and the flashlight adjusted so that as the light is turned on again it will be on the left-hand side, one beam width lower, and ready to be swept across the picture again. When he reaches the bottom right-hand corner (after the necessary number of scans), he could extinguish the light and reposition the flashlight to start the scanning all over again.

If the scanning motion could be done quickly enough, his persistence of vision (the ability of the eye to see an image for a fraction of a second after the object has been removed) will enable him to see the entire picture. This is a simplified illustration of sequential (in sequence) scanning, but it illustrates some of the problems (largely those of speed and control) involved.

Obviously, the picture could have been scanned in a number of ways. The scan could have moved from top to bottom or it could have been circular, starting at the center and moving outward in larger and larger circles. In this country, television scanning proceeds from left to right, beginning at the top left side.

In the Iconoscope, scanning is accomplished in the following manner. The electron beam of small diameter is formed and given the desired velocity by the electron gun located in the neck of the tube (fig. 10-26). Deflection of the electron beam across the mosaic is accomplished by the deflection coils that are positioned around the neck of the tube.

A simplified illustration of scanning in the Iconoscope camera tube is shown in figure 10-28. The electron beam begins its scan at the upper left-hand corner of the mosaic and moves horizontally (in this example) along line 1 toward the right. The globules shown in the illustration are exaggerated in size in order to simplify the illustration. All of the globules in line 1 are in the bright part of the mosaic. Therefore, they have lost the same number of electrons and have accumulated uniform positive charges. As the beam sweeps across these globules, the charges are neutralized, and a relatively steady current flows from the metal coating of the mosaic plate down through *R* in figure 10-26, returning through the *B* supply to the electron beam and back to the associated globules. The same situation prevails while line 2 is being scanned.

A portion of the image (one rectangle within another) is located in line 3, and there will not be a steady flow of current through *R* as the beam traverses this line. The flow is steady until the fourth globule is reached. From four through thirteen the globules have been charged only slightly, and this dsicharge current through *R* is slight when the beam sweeps across them. Beginning with number fourteen, the output current increases again. The same reasoning may be applied to lines 4 and 5. The relative strengths of the signal currents are shown at the bottom of the figure.

If the globules are extremely small and close together, and the image has great detail, there will be many changes in current during the course of a single scan. (It is assumed that the cross-sectional area of the electron beam is small.) The flow of these tiny pulses of current down through *R* (fig. 10-26) develops signal voltages at the input of the amplifier tube. In order that all of these signal voltages may be passed through the amplifier it must be capable of passing a wide band of frequencies.

The Problem of Flicker

The eye retains an image for a fraction of a second (about 1/15 second) after the image is formed on the retina. This characteristic of the eye is utilized in moving pictures and television. Actually, it is because of this characteristic that it is possible to have moving pictures or television.

Moving-picture films are composed of a series of individual pictures (frames) that are shown on the screen in quick succession. The illusion of motion comes about because the figures may be displaced slightly in succeeding frames; and if enough frames are shown per second, the figures appear to move because of the rapid sequence of the frames and the persistence of vision. At approximately 15 frames per second the motion appears continuous, but

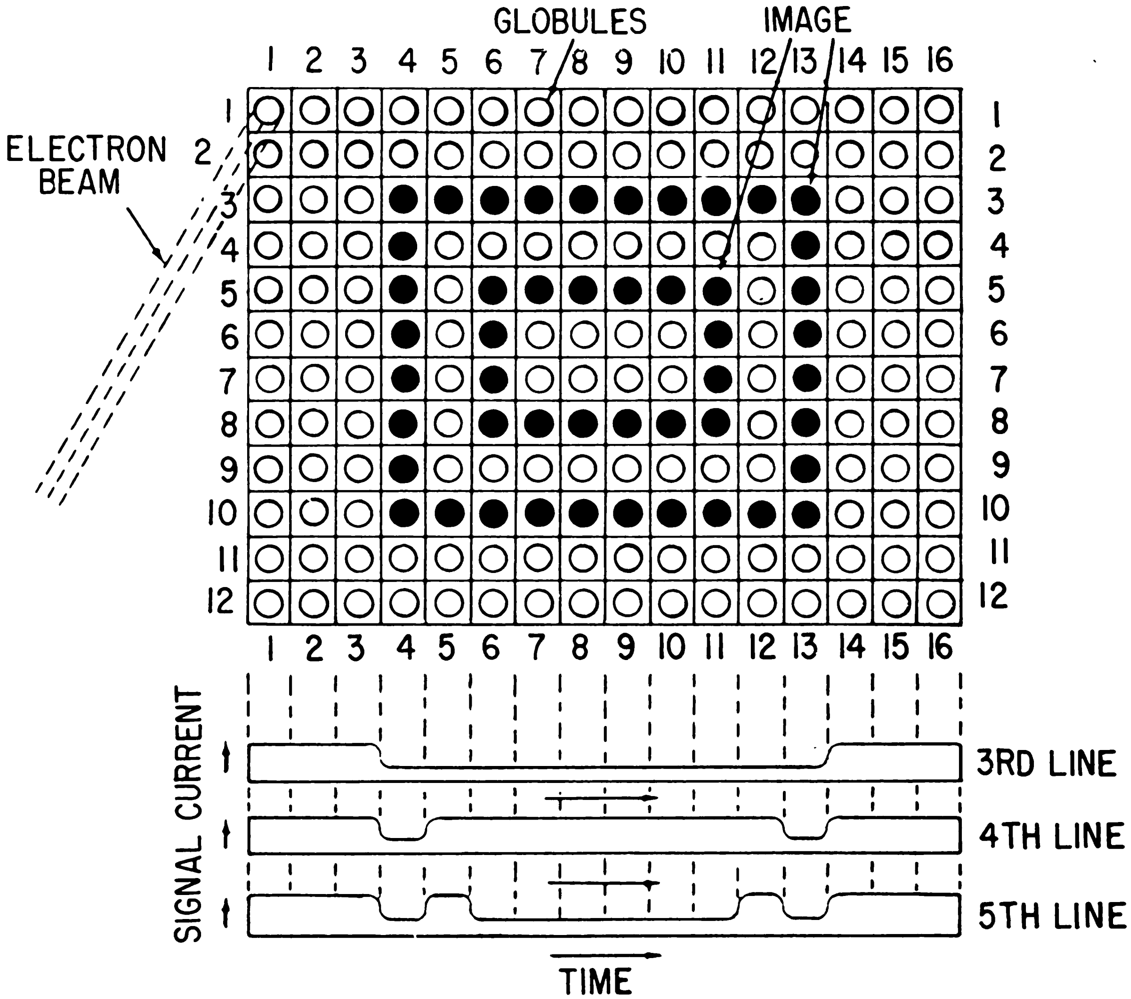


Figure 10-28.—Simplified illustration of scanning.

there is a pronounced flicker. At 24 frames per second, some flicker is present; however, it is much less objectionable than at 15 frames per second. To reduce the flicker still further, a special shutter arrangement is used. The shutter cuts off the light from the screen while a new frame is moved into position. It also cuts off the light from the screen once more while the picture frame is stationary. Thus the shutter divides the presentation of every frame into two equal time intervals. This has essentially the same effect as increasing the frame frequency to 48 frames per second.

In television, scanning must be arranged to prevent flicker and to keep bandpass requirements within practical limits. Another problem that must be overcome is that of shifting the electron beam downward one beamwidth after a line is scanned. These problems—flicker, bandwidth, and electron beam shift—are overcome by interlaced scanning.

If the entire picture is presented to the eye 60 times each second, no flicker will be noticed. Interlaced scanning, while presenting only 30 complete pictures per second, creates the illusion of twice that number.

Interlaced scanning is illustrated in figure 10-29. Bandpass considerations, the problems of synchronization, and the necessity for detail lead to the choice of 525 horizontal scanning lines per frame. To reduce flicker by means of interlaced scanning, the electron beam scans the odd-numbered lines first and then the even-numbered lines. Thus, two scans (fields) are necessary to complete one frame. For example, as shown in figure 10-29, the

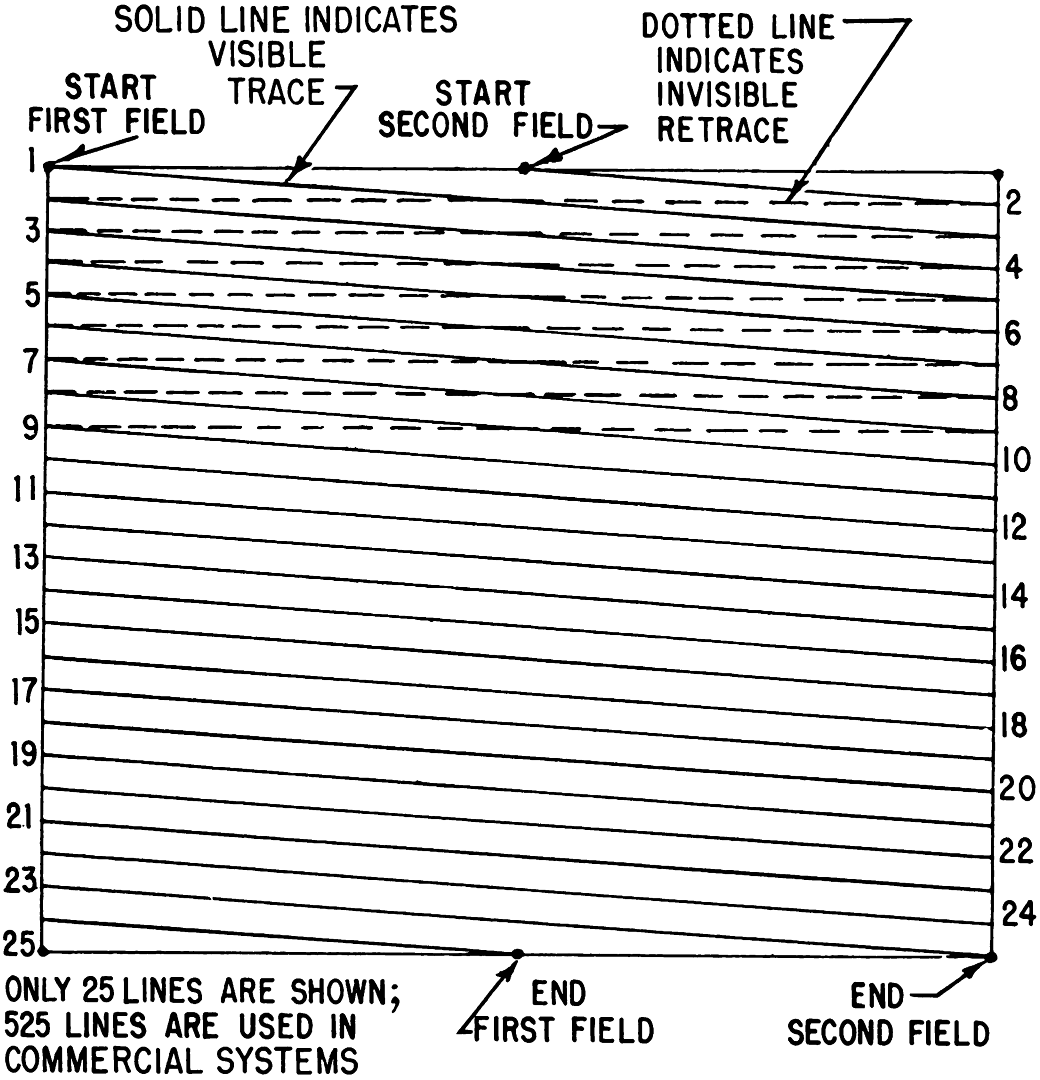

SOLID LINE INDICATES VISIBLE TRACE
DOTTED LINE INDICATES INVISIBLE RETRACE
START FIRST FIELD
START SECOND FIELD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
ONLY 25 LINES ARE SHOWN; 525 LINES ARE USED IN COMMERCIAL SYSTEMS
END FIRST FIELD
END SECOND FIELD

Figure 10-29.—Interlaced scanning.

sweep for the first field begins on the left side of line 1. The beam moves across the image plate at a slight downward angle (pulled downward by the vertical deflection coils). At the end of the line, the electron beam is blanked out during the retrace to the left side of line 3. This process is continued until the middle of line 525 is reached (only 25 lines are shown in the figure). Therefore, 262.5 lines are scanned in the first field. When the beam reaches the middle of the last line, it is blanked out and returned to the middle of line 2 where the trace for the second field starts. The even-numbered lines are scanned in sequence until the end of line 524 is reached. At this time one frame has been completed. At that instant the beam is blanked out and returned to the beginning of line 1, and the whole process is repeated.

Note that as the beam moves across the screen, it drops linearly from line 1 to line 3. This linear drop accomplishes two things: (1) line 2 is left vacant for interlaced scanning, and (2) the beam drop from one scan to the next occurs over the relatively long period of one sweep. If the beam were swept straight across the screen, it would be necessary to drop it rapidly to the next line. This would create quite a problem in engineering.

In order to keep the movement of the electron beams in both the camera and receiver picture tubes in step, and in order to blank out the signals from the picture tube during the horizontal and vertical retrace periods, synchronizing (sync signals) and blanking signals are sent out by the transmitter.

TV TRANSMITTER AND RECEIVER

An explanation of the overall job of a TV transmitter and receiver and the series of events that produce picture transmission and reception will now be given.

It has already been shown how the picture is taken from the camera tube (Iconoscope) by the electron beam scanning process. As the electron beam neutralizes each small capacitor (globule), the current that flows through *R* (fig. 10-26) is representative of some degree of light intensity. The amount of current from each globule is determined by the amount of light striking that globule. Current flow through *R* is the video signal and is applied to a video amplifier. This video signal will eventually be transmitted along with the necessary control pulses.

In order to reconstruct a picture on the CRT of the receiver, it is necessary that the electron beam in the receiver follows exactly the sweep of the beam in the transmitter. For instance, when the transmitter beam is scanning the picture (fig. 10-28), each globule, when neutralized, will cause a current to flow that represents the amount of light striking it. When globule number 1 is scanned in the transmitter, then the receiver electron beam must be in that exact position, (upper left corner), in order to reproduce the intensity of globule number 1 in the correct spot.

Similarly, as each succeeding globule is scanned, the receiver electron beam must be in the correct spot to reproduce it. This means that the electron beam in the receiver must move exactly in step with the beam in the transmitter camera. It would be useless to have the transmitter transmitting the video from globule number 1 if the receiver electron beam was reproducing that video in spot number 4. The transmitter scanning beam and the receiver electron beam must be synchronized to move together, so that as each globule is neutralized in the camera its signal will appear in the proper spot on the receiver CRT. Synchronization is accomplished by sync pulses that are transmitted along with the video signal.

Signal Bandwidth

The Federal Communications Commission (FCC) specifies certain conditions for any type of radio operation. In television transmission the FCC specified that the television signal be restricted to a bandwidth of 6 mc. for each channel in the TV broadcasting spectrum. It also specified that the signal for each channel be divided into two main portions, one for the audio signal and one for the composite video signal. The frequency breakdown of the TV signal is shown in figure 10-30.

This frequency breakdown applies to each channel in the TV spectrum, and is explained in the following manner. For practical reasons the lower sideband cannot be completely suppressed, and 1.25 mc. of it must be transmitted. This portion is referred to as the vestigial sideband. The picture signal carrier, therefore, is 1.25 mc. above the lower frequency limit of its assigned channel. Consider channel 2. The FCC assigned a frequency of 55.25 mc. for the channel 2 picture carrier frequency. The lower limit of channel 2 would then be 54.00 mc. and the upper limit 60.00 mc.; 60 mc. is also the lower frequency limit of channel 3 whose assigned carrier frequency is 61.25 mc.

Figure 10-30 depicts graphically that the picture carrier signal is 1.25 mc. above the lower frequency limit, that the video covers a 4 mc. spread from 55.25 mc. to 59.25 mc., and that the sound carrier is 4.5 mc. above the picture carrier. The sound signal is frequency modulated and occupies a bandwidth of 50 kc., its center or carrier frequency being 5.75 mc. above the lower frequency limit of the assigned channel. Maximum permissible deviation of the sound signal is ±25 kc. from its carrier.

In summary, the following should be remembered about the frequency spread of each TV channel. The video is amplitude modulated and occupies 4 mc. of the allotted 6 mc. spread. The sound is frequency modulated and occupies 50 kc. with a center frequency that is 4.5 mc. above the picture carrier frequency. The vestigial sideband occupies 1.25 mc., and is at the low end of the band.

Composite Video Signal

In connection with the discussion that follows, refer to figure 10-31. All the information necessary to reproduce a scene in a TV receiver is contained in the composite video signal. Besides the picture video, the signal contains blanking and synchronizing pulses. Figure 10-25 shows a block labeled "sync and sweep circuits" in the receiver. This block contains two oscillators, the horizontal and the

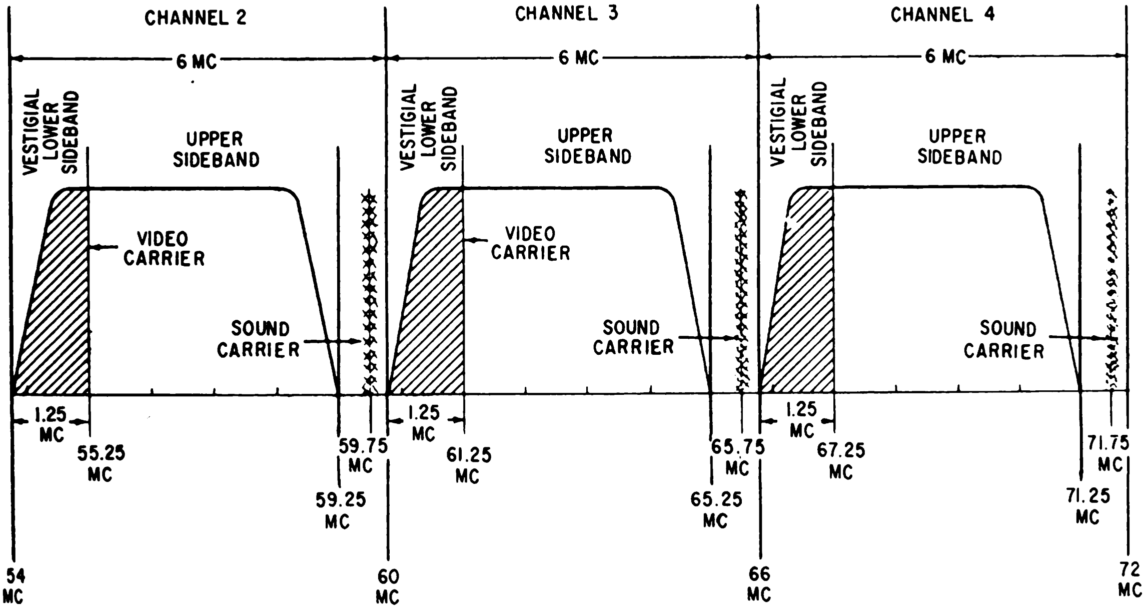


Figure 10-30.—RF spectrum for TV channels 2, 3, and 4.

vertical. The horizontal oscillator is triggered to sweep the electron beam across the scope in step with the camera scanning beam. Because each frame contains 525 lines, and 30 frames are produced in one second, then the horizontal oscillator is triggered 525 x 30, or 15,750 times each second. This, then, is the horizontal oscillator frequency.

The vertical oscillator has the job of returning the electron beam to the top of the scope after it completes each field. Remember that because of interlaced scanning, one picture frame contains two fields. To produce 30 frames per second, the electron beam must sweep 60 fields. (Refer to fig. 10-29.) Each time the electron beam reaches the bottom of a field, the vertical oscillator is triggered and returns the beam to the top of the screen. Sixty cycles per second, then, is the frequency of the vertical oscillator.

To insure that the horizontal and vertical oscillators operate at exactly the right time to synchronize the receiver electron beam with the electron beam in the transmitter camera, synchronizing pulses are sent with the video signal. Also, in order to blank the scope so that retrace lines are not seen as the beam is pulled quickly back to the left of the screen after each line and to the top of the screen after each field, blanking pulses are sent with the video signal. In the composite video signal the synchronizing pulses are actually superimposed on the blanking pulses. (See. fig. 10-31.)

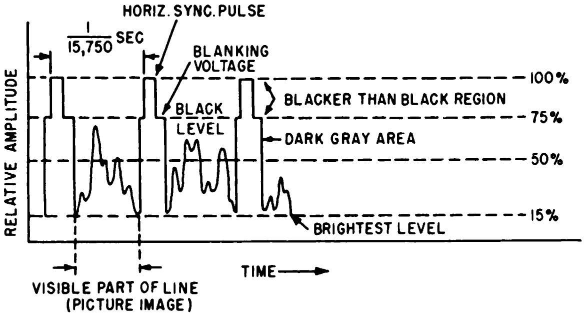


Figure 10-31.—Two complete lines.

Remembering that there are 15,750 lines traced in one second, it follows that a line is traced each 1/15,750th of a second.

In figure 10-31, note the division of voltage amplitude of the composite signal. The signal is applied to the CRT in such a manner that as the voltage amplitude increases, the picture becomes darker. Conversely, as signal amplitude decreases the picture becomes brighter. If enough signal is applied to the CRT, it is possible to cause the picture to become completely black. The first 75 percent of the video voltage range is the picture area, and at that point (75 percent of voltage range) the screen is completely black. The blanking pulses that occur after each line is traced have an amplitude of 75 percent of the video voltage range, and completely blank the scope during retrace time.

The horizontal sync pulses are higher in amplitude than the blanking pulses and are sent at the same time. As can be seen in figure 10-31, they are superimposed on the blanking signal. Because 75 percent of the video range is the black level, any voltage greater than that is said to be in the blacker than black region. Horizontal sync pulses are in the blacker than black region.

When the contrast control of a television receiver is turned to give greater contrast, the picture becomes darker. Likewise, turning the control in the opposite direction causes a lighter, or washed-out picture. If contrast is reduced below the 15 percent level, virtually no picture will be seen, and the screen is at its brightest.

Serrated Vertical Pulse

The vertical pulse that returns the electron beam to the top of the screen is shown in figure 10-32. This pulse is sent after each field is completed, and is serrated (broken up into smaller pulses) to prevent interference with the horizontal oscillator action. Because of the long RC time constant in its input, this pulse looks like one long uninterrupted pulse to the vertical oscillator. But to the horizontal oscillator, with a short RC input, it appears as the narrow pulses shown. The horizontal oscillator must never be permitted to become unsynchronized, not even for the few microseconds needed to reposition the electron beam to the top of the screen. For that reason the vertical pulse is serrated, and the horizontal oscillator works continuously even though no lines are seen during the vertical retrace time. It is interesting to note that a few lines are lost during vertical retrace time.

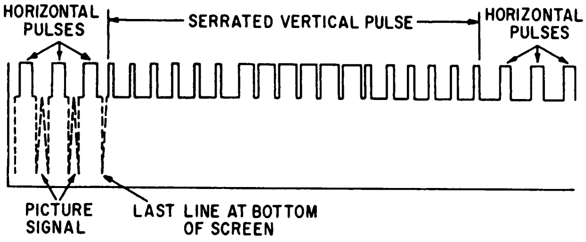


Figure 10-32.—Serrated vertical sync pulse.

Sync Separation

Both the horizontal and vertical sync signals are received on one antenna and go through some receiver circuits simultaneously. In fact, they usually remain together throughout the video IF stages. Somewhere in the receiver they must be separated, because the two oscillators are separate and distinct circuits with separate inputs. The exact mechanism of the separating action is not discussed, but separation is accomplished by use of RC time constants that will pass the desired pulse and reject the other. Such arrangement is shown in block form in figure 10-33.

As stated previously, the blanking pulses and the horizontal and vertical synchronizing (sync) pulses are amplified in the various stages along with the video information. The video signals and the blanking pulses are applied to the picture tube. However, the sync signals are removed from the composite video signal (generally in the last video stage) and applied to the horizontal and vertical sync circuits. This is sometimes called clipping.

After the vertical and horizontal sync signals have been removed (clipped) from the video signal, they must be amplified (if necessary) and separated by means of filters. Following this, they are amplified and reshaped, according to the needs of the system, before they are applied to the oscillators. A block diagram of the synchronizing circuits is shown in figure 10-33.

The horizontal sync signal triggers the horizontal oscillator at exactly the right instant to maintain the proper synchronization between the horizontal sweep in the receiver picture tube and the horizontal sweep in the transmitter camera tube. The output of the horizontal oscillator is formed into a sawtooth waveform; it is then amplified to the horizontal deflection coils.

The vertical sync signal triggers the vertical oscillator at the right instant to maintain the proper synchronization between the vertical sweep in the receiver picture tube and the vertical sweep in the transmitter camera tube. As in the case of the horizontal oscillator output, the vertical oscillator output is formed into a sawtooth wave (that will be further modified); it is then amplified and applied to the vertical deflection coil.

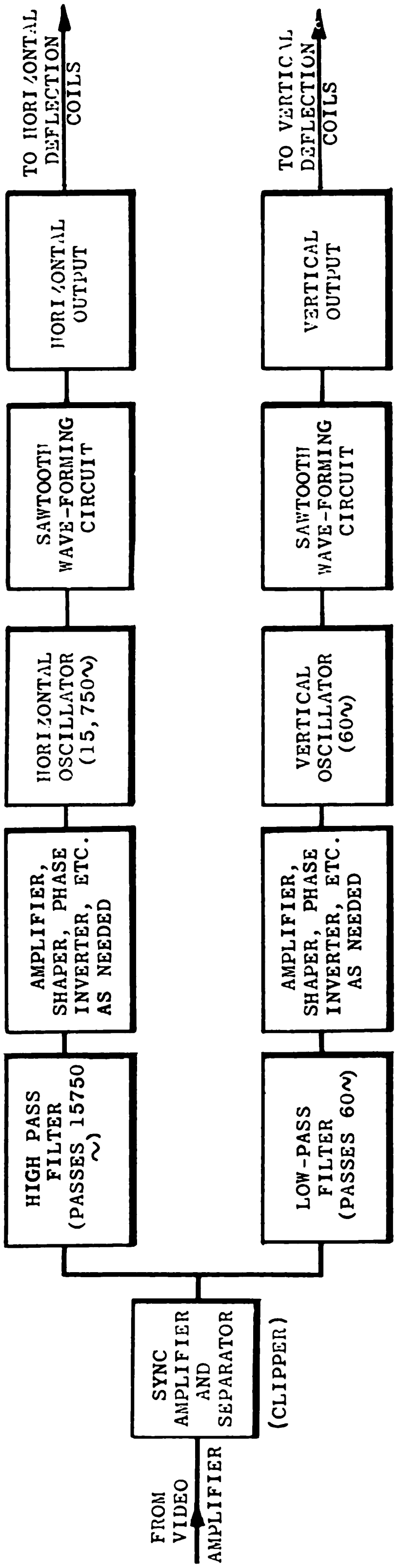
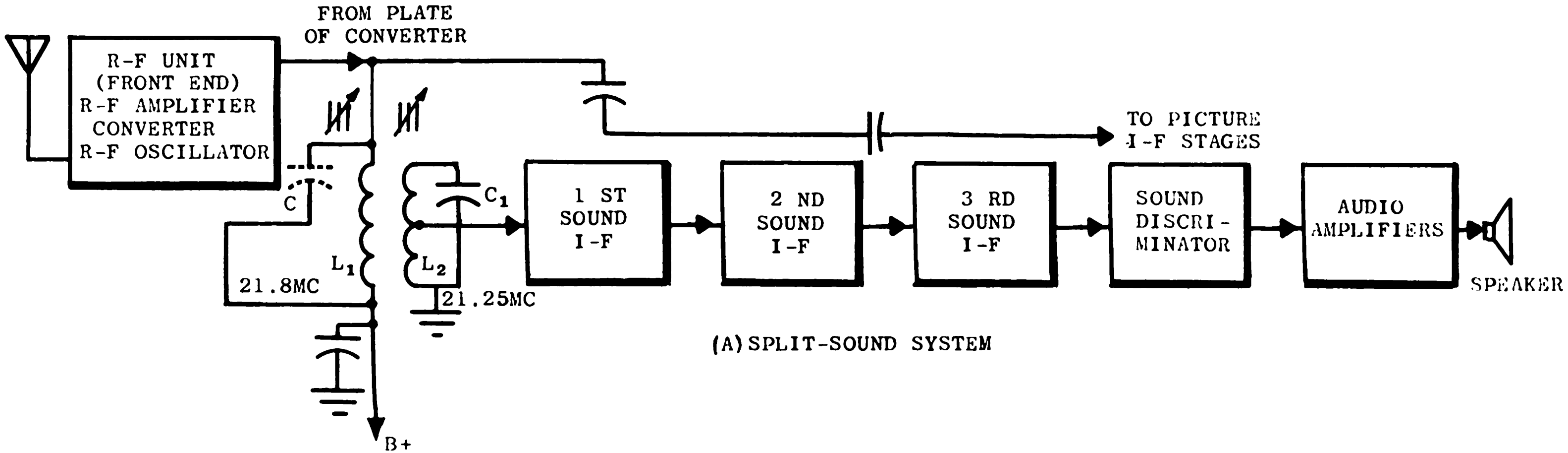
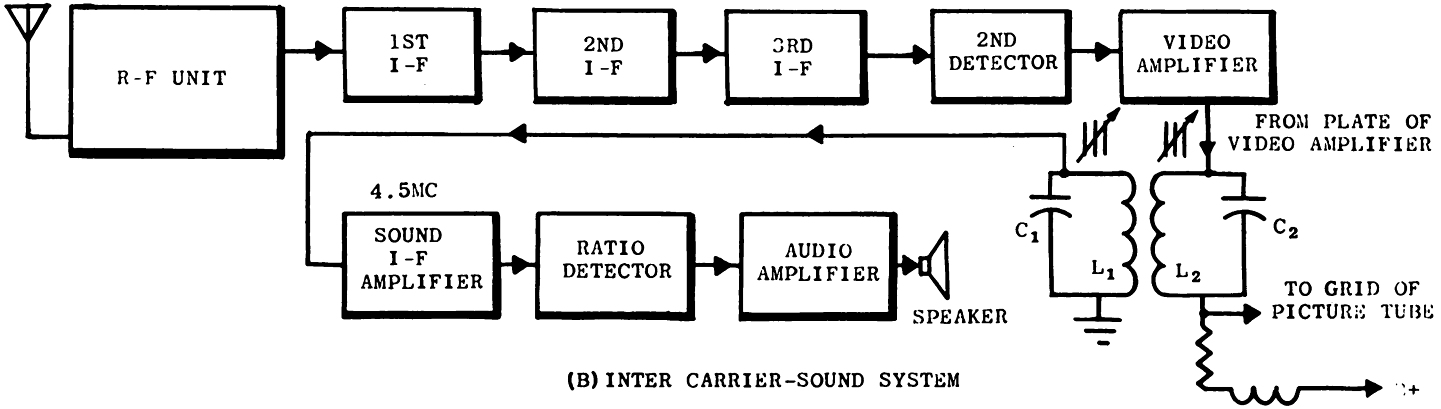

FROM VIDEO AMPLIFIER
SYNC AMPLIFIER AND SEPARATOR
(CLIPPER)
HIGH PASS FILTER (PASSES 15750 ~)
LOW-PASS FILTER (PASSES 60~)
AMPLIFIER, SHAPER, PHASE INVERTER, ETC. AS NEEDED
AMPLIFIER, SHAPER, PHASE INVERTER, ETC. AS NEEDED
HORIZONTAL OSCILLATOR (15,750~)
VERTICAL OSCILLATOR (60~)
SAWTOOTH WAVE-FORMING CIRCUIT
SAWTOOTH WAVE-FORMING CIRCUIT
HORIZONTAL OUTPUT
VERTICAL OUTPUT
TO HORIZONTAL DEFLECTION COILS
TO VERTICAL DEFLECTION COILS

Figure 10-33.—Block diagram of synchronizing circuits.



(A) SPLIT-SOUND SYSTEM



(B) INTER CARRIER-SOUND SYSTEM

Figure 10-34.—Television sound systems.

Sound Systems

Figure 10-34 shows typical TV sound systems. The two systems are termed "split-sound" and "intercarrier." The sound system of a television receiver is essentially the same as that of an FM receiver, as explained in *Basic Electronics*, NavPers 10087.

The main distinction between the two sound systems is the method used for IF amplification. When the split-sound system is employed, the sound is usually separated from the composite signal at or near the first video IF. However, it may be taken off anywhere before the video detector.

Intercarrier sound systems remove the sound from the composite signal after the video detector. This system saves several stages of amplification and is used almost universally in present-day sets.

Television System

The transmitter camera produces the picture video signal by neutralizing the globules of the mosaic. (Refer to fig. 10-25.) The scanning electron beam is caused to scan the mosaic at a rate determined by the synchronizing pulses from the sync generator. This same sync generator also adds its pulses to the picture video signal to be transmitted to the receiver.

Sound, being frequency modulated, is produced and controlled apart from the video and sync signals, and is transmitted separately.

The receiver must do several things. It must apply the picture video to the electron beam of the CRT, and clip or separate the synchronizing signals from the composite signal. Further, the sync signals must be directed to their respective oscillators to synchronize the receiver electron beam with that of the transmitter camera.

The receiver must also provide a separate sound system for the FM signal.

QUIZ

1. In the filter method of single-sideband suppression, the filters should be inserted in the transmitter at
   a. a level of high power
   b. a level of medium power
   c. a level of low power
   d. any power level

2. One of the prime requirements of a good single-sideband receiver is
   a. wide bandpass and high gain
   b. excellent stability with narrow bandpass and a stable beat-frequency oscillator
   c. dual conversion
   d. a product detector

3. A spot of light shining on the mosaic of an Iconoscope would
   a. reduce the current flow in that section
   b. not affect the current flow in that section
   c. increase the current flow in that section
   d. produce no current flow change in that section, but voltage would increase

4. The talking power of a 250 watt single-sideband transmitter, being received on a narrow bandwidth receiver, is equal to
   a. 250 watts of double sideband 100 per cent modulated
   b. 400 watts of double sideband 100 per cent modulated
   c. 1,000 watts of double sideband 100 per cent modulated
   d. 500 watts of double sideband 100 per cent modulated

5. In SSB, a balanced modulator accomplishes which of the following?
   a. Cancels the carrier and only the upper and lower sidebands will appear in the output
   b. Cancels the audio in the output providing the audio is fed in push-push 45 degrees out of phase
   c. Cancels the upper sideband only
   d. Cancels the lower sideband only

6. Single-sideband transmitters employing either the filter or phasing method of sideband suppression use
   a. high-level modulation
   b. low-level modulation
   c. either screen or cathode modulation
   d. clamp-tube modulation

7. Remanent induction, in connection with tape recorders, refers to
   a. gap flux
   b. permanent magnetization of the tape
   c. erase head bias
   d. record head bias

8. The TV system that enables transmission of the image impulses by elements is the
   a. intercarrier system
   b. interlace system
   c. mosaic system
   d. scanning system

9. In SSB, when the audio signal is fed push-pull into the balanced modulator, the
   a. carrier is also fed in push-pull
   b. carrier is fed in push-push
   c. output is the difference of the two sidebands
   d. output is the carrier and the upper sideband

10. In the phasing method of single-sideband suppression using two balanced modulators, the carrier and modulating signals are
    a. applies directly to one balanced modulator and phase-shifted 90 degrees before being applied to the other balanced modulator
    b. phase-shifted 90 degrees before being applied to both balanced modulators
    c. phase-shifted 45 degrees before being applied to either balanced modulator
    d. phase-shifted 180 degrees before being applied to either balanced modulator

11. When two single-sideband stations are being received at the same time, the operator at the receiver will be
    a. unable to copy either station
    b. able to copy both stations
    c. able to receive only station number 1
    d. able to receive only station number 2

12. The sync signals for a TV receiver are
    a. generated within the receiver
    b. not needed
    c. transmitted by the TV station
    d. lower in amplitude than video (picture) signal

13. Flicker has been eliminated in present-day TV by
    a. increasing the number of lines
    b. reducing the scanning frequency
    c. decreasing the persistence of the CRT
    d. effectively doubling the frequency of illumination with interlaced scanning

14. One of the advantages of single sideband is that
    a. it occupies more of the radiofrequency spectrum
    b. it occupies the same amount of the radiofrequency spectrum as double sideband
    c. it uses less of the radiofrequency spectrum
    d. less stability is needed of the oscillators at the transmitter

15. The output amplifier of a single-sideband transmitter is usually biased class
    a. C
    b. A
    c. C using high-level modulation
    d. AB and always linear

16. One reason wire recorders are being replaced by tape recorders is because
    a. tape recorders are less bulky
    b. tape is less expensive
    c. the signal/noise ratio is better, plus improved frequency response
    d. circuitry is less complex in tape recorder

17. In TV, the horizontal sweep oscillator frequency when properly synchronized, is
    a. 60 c.p.s.
    b. 15,750 c.p.s.
    c. 31,500 c.p.s.
    d. 4.5 mc.

18. In order to transmit either upper or lower sideband when using a mechanical filter,
    a. only one mechanical filter is needed and the carrier must be RF phase-shifted before being injected into the filter
    b. two mechanical filters are needed and the carrier must be RF phase-shifted by 90 degrees before being applied to the filter
    c. two mechanical filters are used, with a method of switching the desired filter into the circuit
    d. three should be used in order to be able to transmit both sidebands and eject the carrier

19. In SSB, the maximum allowable drift between transmitter frequency and receiver frequency is about
    a. 100 cycles for good voice reception
    b. 150 cycles for good voice reception
    c. 50 cycles for good voice reception
    d. 250 cycles for good voice reception

20. Recording tape is composed of
    a. plastic particles deposited on iron backing
    b. any nonmagnetic substance on a plastic backing
    c. any magnetic substance deposited on a magnetic backing
    d. iron oxide particles on a plastic backing

21. A television receiver is synchronized by
    a. the 60-cycle a-c input
    b. high stability multivibrators within the set
    c. sync pulses contained in the received signal
    d. the sweep applied to the picture tube

22. The serrations of the vertical sync pulses
    a. maintain vertical sweep generator synchronization
    b. start the blanking pulse
    c. allow the integrator network time to charge
    d. maintain horizontal oscillator synchronization during vertical retrace time

CHAPTER 11

AIRBORNE ELECTRONIC NAVIGATION EQUIPMENT

Electronic navigation is a term embracing many systems and instruments. As an AT you will be required to maintain, and, in some instances, operate various electronic equipments. A discussion of loran, radio direction finders, radio markers, radio ranges, instrument landing systems, omnidirectional ranges, distance measuring equipment, and infrared is given in this chapter.

Loran

LORAN is an abbreviation of the terms LOng RAnge Navigation. It is reliable for both air and surface navigation in all kinds of weather conditions. Loran signals can be received even during violent storms.

Loran is a long-range navigational system developed primarily to provide a means for making geographical fixes by the use of radio signals. With loran equipment, the navigator determines his position by measuring the difference in the time required for radio pulses to arrive from two or more pairs of land-based transmitters. Each measurement is called a fix. Two or more fixes are required to determine the position accurately.

The system is a valuable aid to air navigation since loran fixes can be made quickly and accurately both by night and by day. Under ordinary conditions, an initial fix can be made in about three minutes. Thereafter a fix can be established in one minute or less. Operation is unhindered by fog and foul weather, and the signals are available over long distances. Newer receivers such as the AN/APN-70 provide dual delay channels giving a direct time difference reading for each line of position required for a fix, on a direct reading counter.

Standard loran transmissions are made on four frequency channels situated between 1.7 and 2 megacycles. Operation at these frequencies gives long-range coverage, employing both groundwaves and sky waves. The useful range for day operation over sea water is about 700 miles. At night the distance is greater, extending up to 1,400 miles. In addition to standard loran, low-frequency (LF), loran facilities are available which operate on two channels from 90 to 110 kc. and from 170 to 190 kc.

In principle, loran differs from radar in that the airborne (or shipboard) unit simply receives radio pulses broadcast from ground stations, and no reception of echo signals is involved. The basic loran measurement is that of time difference of arriving signals with no regard to the direction from which they arrive; hence, the complicated directional antennas such as used in radar equipment are not necessary. Despite these differences, however, loran is closely related to radar since it is a pulse type of equipment, and it employs radar techniques of time measurement. Also, visual displays of the signals received are made on cathode-ray tubes used as indicators.

The basic principle of the system is illustrated in figure 11-1. The use of the system involves the following procedures:

1. Radio signals consisting of short pulses are broadcast from a pair of ground-based transmitting stations.
2. The signals are received on special loran receivers located in the aircraft or ship.
3. The difference in the time of arrival of corresponding pulses from the two stations is measured on the loran indicator.
4. The value of the time difference is used to identify a line of position on a loran chart. (This is fully explained later.)
5. Two or more lines of position are found by time difference measurements from two or more pairs of stations. The intersection of the lines of position gives the location of the observer.

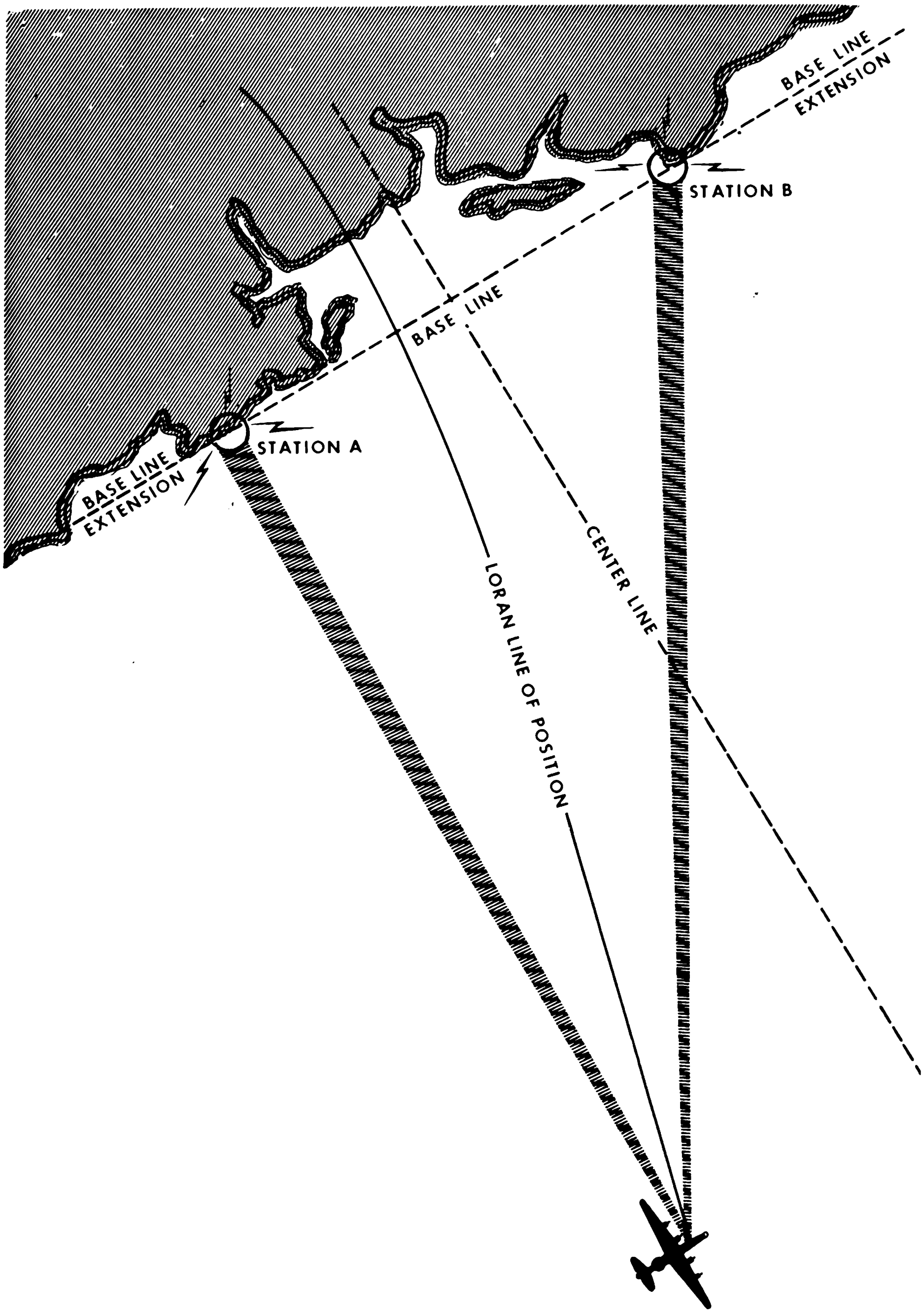


Figure 11-1.—The principle of loran.

As shown in figure 11-1, two stations are necessary to establish a loran line of position. One transmitter, called the MASTER STATION, emits a series of uniformly spaced pulses each second. The number of pulses radiated per second is called the pulse recurrence rate (PRR). At a considerable distance from the master station (usually several hundred miles), a second transmitter, called the SLAVE STATION, sends out a similar series of pulses which are synchronized with the master pulses. The difference in arrival time of the master and slave pulses at the observing station determines the particular

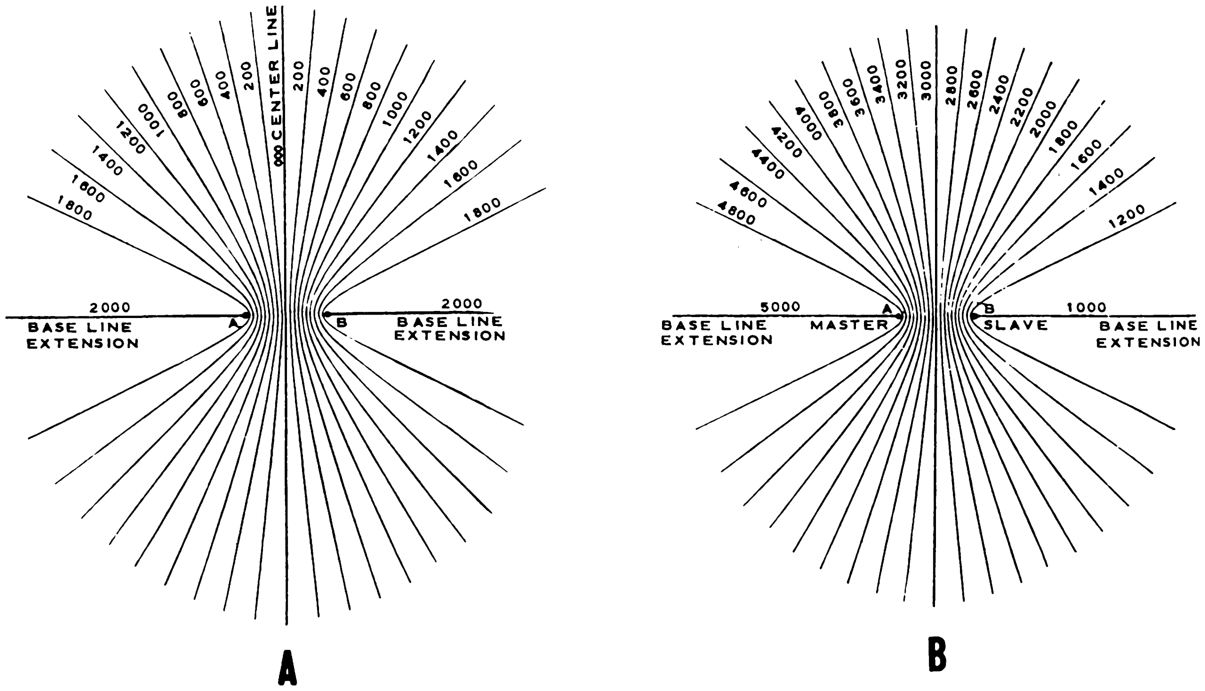


Figure 11-2.–Lines of position. (A) No time delay; (B) 3,000-microsecond delay.

LINE OF POSITION on which the observer is located.

In figure 11-1, the line joining the two stations is called the BASE LINE, and its perpendicular is called the CENTER LINE. The BASE LINE EXTENSION is a straight line drawn beyond either station as a continuation of the base line. Assume that the two stations are sending out pulses simultaneously. Then at any point along the center line, the two signals arrive at the same instant since all points of the line are equidistant from the two transmitters. If the observer is located nearer station A than station B, the A pulse arrives first followed after a measurable time interval by the corresponding B pulse. If the observer moves in a path so that the pulses always arrive with the same time interval, he then traces out a loran line of position.

A number of lines of position can be drawn for each PAIR of loran transmitters as shown in figure 11-2. Each line is labeled with a number indicating the time interval in microseconds between the arrival of the corresponding loran pulses. In (A) zero time difference exists along the center line and maximum time difference along the base line extensions. The curves are hyperbolas since this curve is the path traced by a point which moves so that the difference of its distances from two fixed points remains constant. (For this reason loran is called a hyperbolic system of navigation.)

In (A) of figure 11-2 lines with the same time difference are found on each side of the center line since there is no way of telling which signal is from which station. Hence, if the simultaneous method of signal transmission were used, it would be necessary to identify the signals from each station of a pair. In actual practice the signals are not sent simultaneously, but the slave station pulse is delayed so that at any point the master station pulse is received before the corresponding slave signal. As a result, each line of the family of curves has a different time interval value as shown in (B) of figure 11-2.

The method of staggered, or delayed, pulsing is shown in figure 11-3. The master (or A) station transmits a pulse. An interval of time elapses during which the signal reaches the slave station. The slave station receives the impulses and waits a period of time equal to one-half the pulse recurrence interval plus another period of time called the coding delay. It then emits a pulse. The sum of the travel time, half the recurrence interval, and the coding delay is called the absolute delay. As a result of the delay, the master pulse always

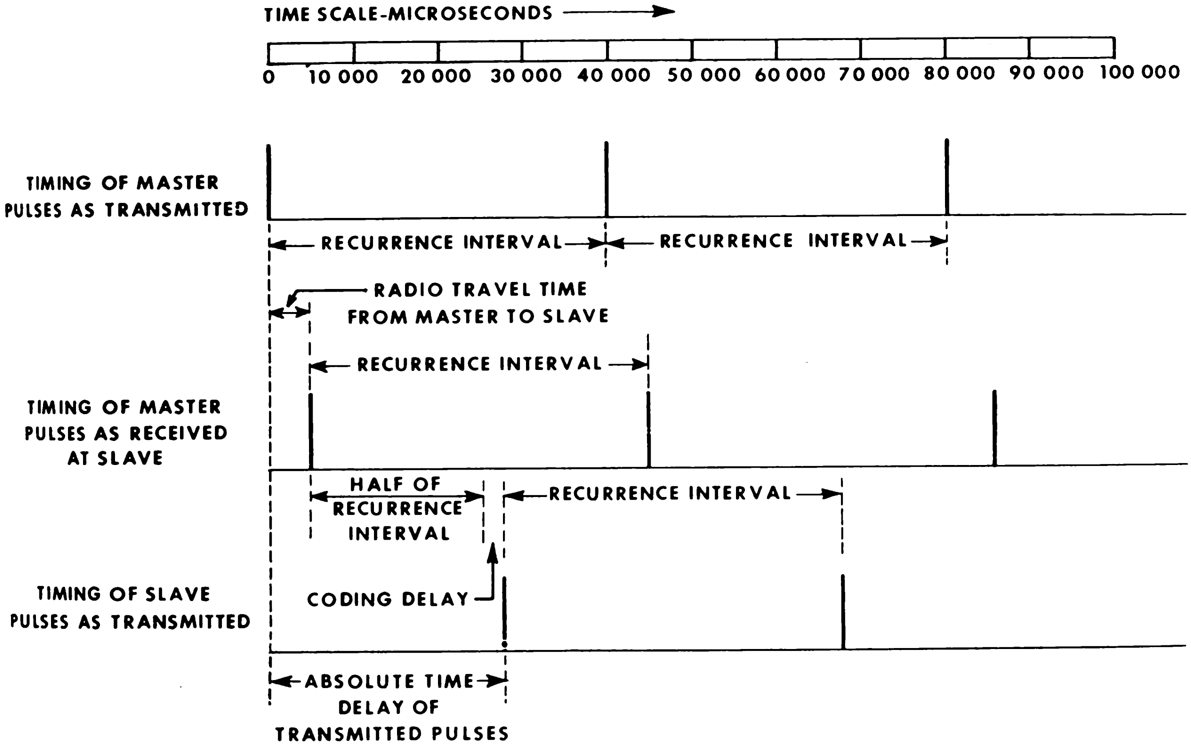

TIME SCALE-MICROSECONDS
0
10 000
20 000
30 000
40 000
50 000
60 000
70 000
80 000
90 000
100 000
TIMING OF MASTER PULSES AS TRANSMITTED
RECURRENCE INTERVAL
RECURRENCE INTERVAL
RADIO TRAVEL TIME FROM MASTER TO SLAVE
RECURRENCE INTERVAL
TIMING OF MASTER PULSES AS RECEIVED AT SLAVE
HALF OF RECURRENCE INTERVAL
RECURRENCE INTERVAL
CODING DELAY
TIMING OF SLAVE PULSES AS TRANSMITTED
ABSOLUTE TIME DELAY OF TRANSMITTED PULSES

Figure 11-3.—Time relationship of actual loran pair.

precedes the slave signal at any point of reception. The difference in arrival time is maximum along the base line extension beyond the master station and minimum on the base line extension beyond the slave transmitter, as shown in (B) of figure 11-2.

For use aboard aircraft and ships the Hydrographic Office publishes loran charts which are standard Mercator charts with loran lines of position superimposed. The lines are computed mathematically, taking into account the coding delay, the curvature of the earth, and other factors. (If required by reasons of security, it would be possible to change the coding delay. A coding correction would then be issued to navigators using the charts. The system would be useful only to persons knowing the proper correction.) The use of the chart in obtaining a loran fix is illustrated in figure 11-4.

A loran chart shows the lines of position of one station pair crossing those of another. In many installations, the two pairs consist of a single master station operating in conjunction with two slave transmitters. This is called double-pulsed transmission and is the type represented in figure 11-4. The common master station emits two sets of pulses. Each set is synchronized with one of the adjacent slave stations. In the figure, the master station is labeled P and the slave stations, R and Q. The combination P-R operates with a pulse recurrence rate that is different from the combination P-Q. Two families of lines are available, and the fix is made by taking measurements on both pairs, locating the observer at point x.

The lines of position on loran charts are indicated by letter-number groups that inform the operator of their characteristics. These are channel number, frequency, basic pulse recurrence rate, specific pulse recurrence rate, and a time difference in microseconds. With these indications, the operator can properly and quickly set the receiver to the desired mode.

When loran fixes are made, the general position of the craft is usually known. The navigator consults the loran chart for that particular area and selects a station pair by setting the receiver controls according to the symbols given on the chart. The principal receiver settings are for channel frequency, basic pulse recurrence rate, and specific pulse recurrence rate.

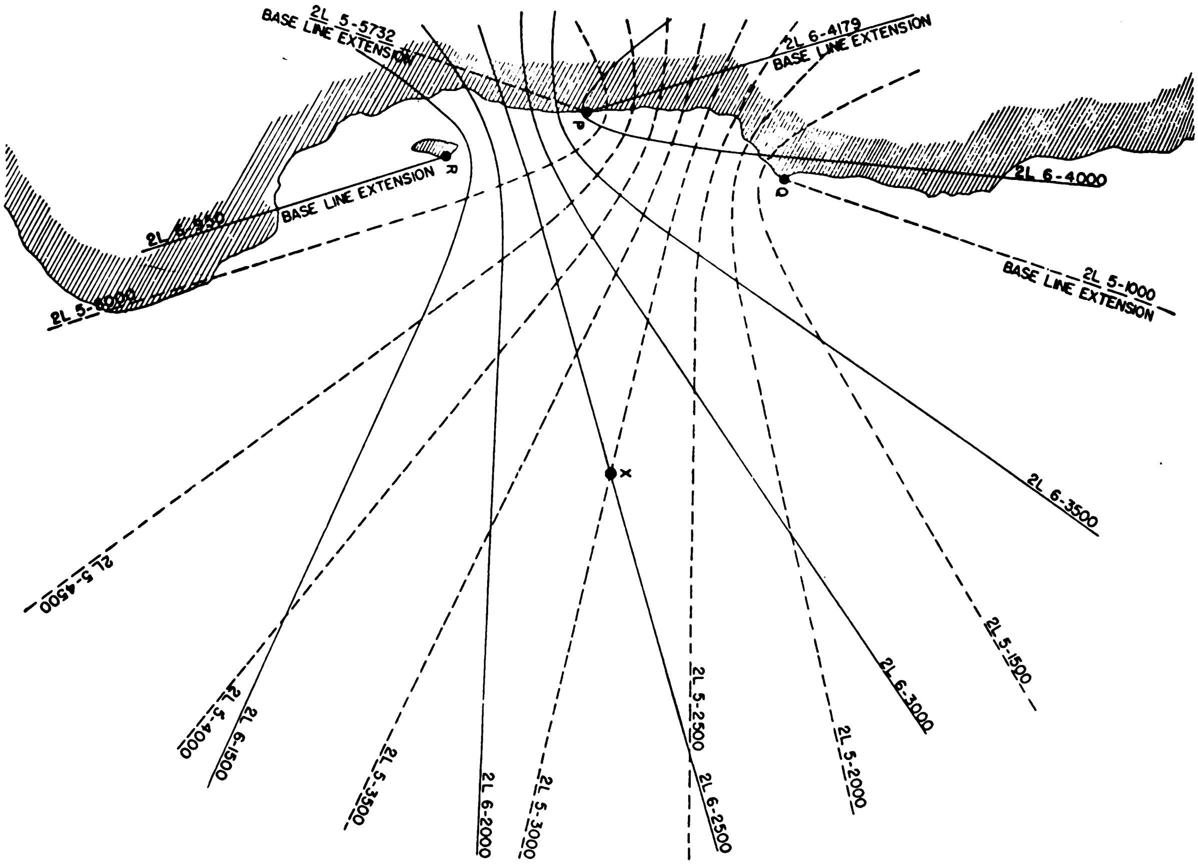


Figure 11-4.—Method of obtaining a loran fix.

Loran stations operate in a portion of the radio spectrum which is extremely crowded; and to conserve space, several station pairs are operated on the same RF carrier frequency. However, each pair emits pulses at a different rate; and by this means, the receiver distinguishes between stations on the same channel. The receiver displays the loran pulses visually on a cathode-ray tube indicator. After channel selection, pulses from many stations are present on the indicator. The desired set is selected by synchronizing the sweep in the indicator with the rate at which the desired pulses occur. When the number of patterns the indicator traces each second is equal to the pulse recurrence rate of the desired station pair, the signals remain stationary on the screen. Pulses from other stations drift across the screen and can be ignored. The general appearance of the indicator display is shown in figure 11-5.

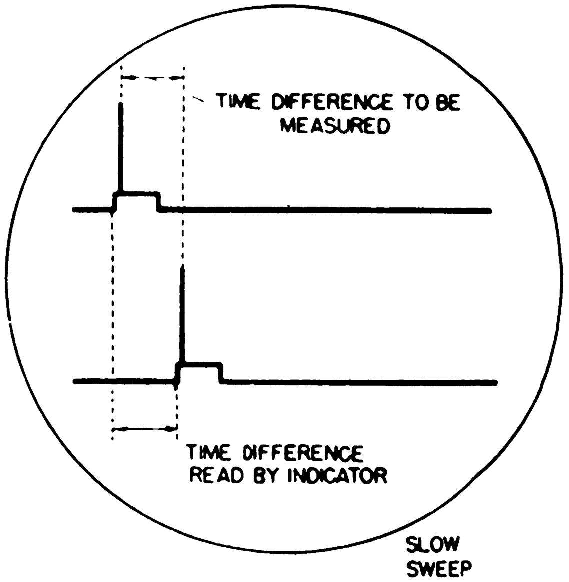

TIME DIFFERENCE TO BE MEASURED
TIME DIFFERENCE READ BY INDICATOR
SLOW SWEEP

Figure 11-5.—Time difference measured on a loran indicator.

The electron beam in the indicator tube traces two time base lines, one above the other. Moving from left to right, it slowly traces the upper line in a period of time equal to one-half the pulse recurrence interval. It quickly retraces, jumping to the left and below. It then traces the lower base line in one-half the recurrence interval before rapidly returning to the start of another top line.

The master station pulse is superimposed on the upper base line and the slave pulse appears on the lower when the receiver is correctly adjusted. The station pulses are displayed above pedestals, rectangular deflections in the time base lines which indicate portions of the display which can be expanded and examined in greater detail for accurate measurement. The time difference to be measured is represented by the horizontal distance between the master pulse on the left and the slave pulse below it to the right. This method of measuring the time difference automatically cancels the fixed delay of one-half the recurrence rate by which the slave pulse was retarded during transmission. The time difference reading is indicated by a counter on present-day direct-reading loran.

As previously mentioned, loran differs from radar in that it does not employ the reflected signal principle. However, since pulse-type transmission and reception are employed, the loran receiver is called a radar receiver. (See fig. 11-6.)

RADAR RECEIVING SET AN/APN-70

Radar Receiving Set AN/APN-70 is an airborne navigational aid used to receive and interpret loran signals. It is installed in bombers, cargo, transport, and similar aircraft. It contains many features which represent improvements in airborne loran receivers, among which are the following:

1. Direct readings of time delay are obtained on decade-type revolution counters. The time intervals appear in digits denoting microseconds on the revolution counters, the number indicated depending on the elapsed time between the master and slave pulses received.
2. Automatic drift control (ADC) is employed. These circuits allow exact synchronism between the recurrence rate of the transmitting stations and the corresponding rates generated in the receiver.
3. A 5-inch cathode-ray tube is used in the indicator unit.
4. Provision is made for navigating along a loran line of position.
5. Many special test points are provided in the set, subassembly construction is used, and adjustment instructions are mounted on the chassis. These features make for greater ease in maintenance and repair.

The major components of the AN/APN-70 are the receiver, the indicator, an antenna coupler, special shock mountings for each of the preceding components, and a viewing visor. The receiver assembly includes an RF RECEIVER unit, the TIMER unit, the DEFLECTION unit, and the POWER SUPPLY.

The RF receiver unit of the AN/APN-70 set is designed to operate over the standard high-frequency loran band from 1,700 to 2,000 kilocycles, and on the two low-frequency channels from 90 to 110 kc and 170 to 190 kc.

The AN/APN-70 receiver uses the same antenna used by other electronic devices (such as communication receivers) in the same airplane. The antenna coupler serves to isolate the loran equipment and to prevent interaction with the other electronic systems which share the common antenna. In addition to isolation of the receiver, the coupler unit also provides a means of matching the unit to the characteristics of different antennas, for amplifying signals to which the set is tuned, and for attenuating unwanted reception. Four stages of amplification are contained in the antenna coupler together with the associated impedance-matching and attenuation circuits.

Basic Principle of Operation

The receiver gives a direct reading in microseconds of the indicated time difference between the arrival of the master and slave pulses received from the loran transmitting stations in use. Two variable time intervals are generated within the receiver. A reading is obtained by comparing a variable time interval with the elapsed time between reception of the loran pulses, the comparison being made by means of the display on the indicator screen. Each variable time interval is controlled by a crank located on the receiver panel; and when the time interval has been adjusted to coincide with the received interval minus one-half the recurrence interval, the indicated time difference can be read on the associated counter.

Since the receiver contains two delay systems, one reading for a standard loran pair can be retained while the second value from another pair is being taken. This is comparable to using two older type loran receivers

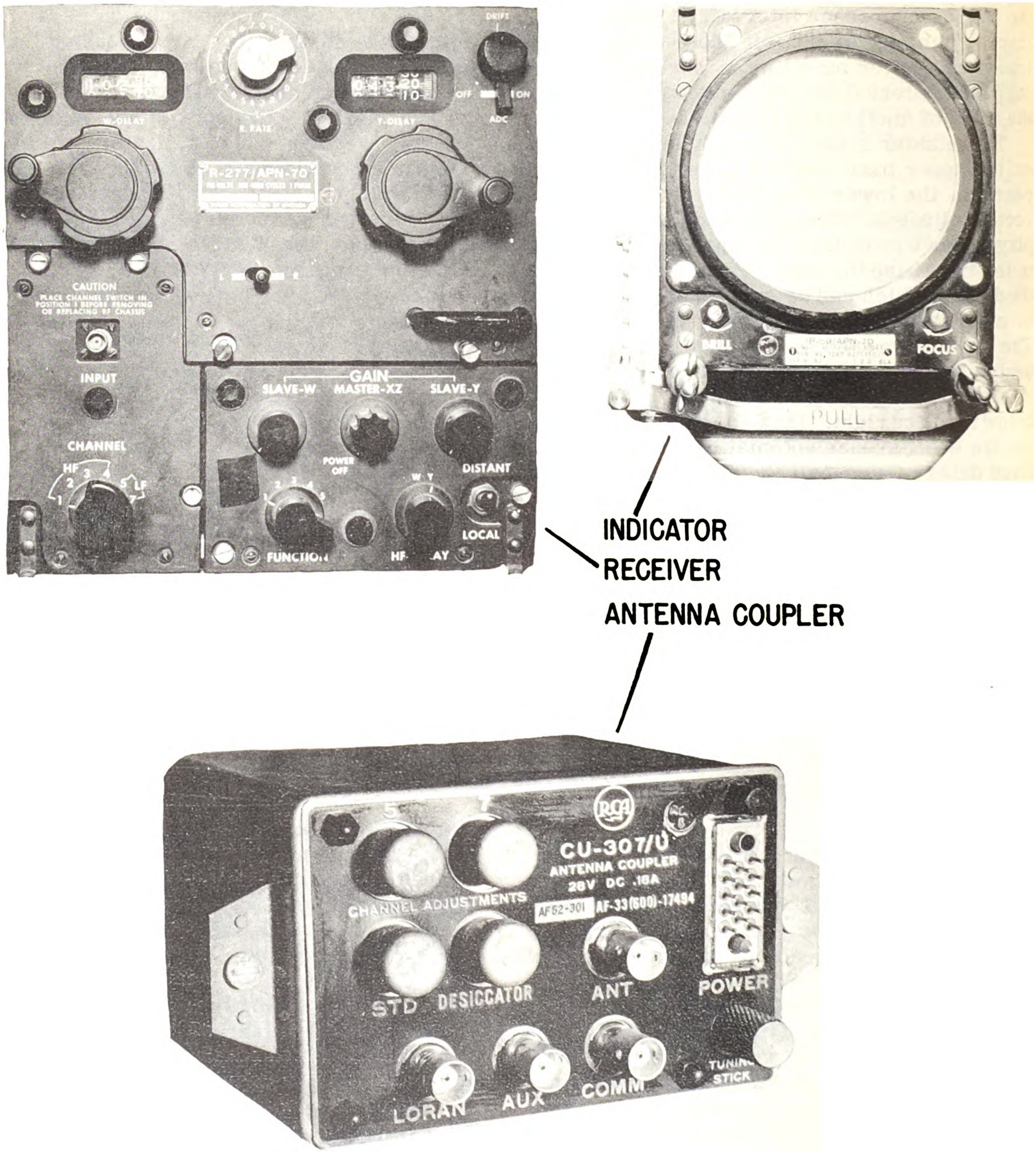


Figure 11-6.—Radar Receiving Set AN/APN-70.

simultaneously. Also, if one delay system fails, the equipment is still usable since the two time-difference readings required for a fix can be obtained from the remaining operating delay system.

The AN/APN-70 equipment provides for reception of low-frequency (LF) loran stations; and in this type of operation, the two time-difference readings corresponding to lines of position appear simultaneously on the revolution counter dials. The simultaneous readings are based on triad operation of the transmitters. The LF loran triad consists of a master station which controls two slaves. The master transmitter is pulsed at twice the recurrence rate of the slaves while the slaves emit pulses at the same recurrence rate. One pulse from each slave is sent during each recurrence period, L, and the master pulses occur at intervals of L/2. The master pulses are called X and Z and the slave pulses are known as Y and W. During reception of signals from LF triads, all four pulses appear on the indicator in the sequence X-Y-Z-W. In order that the pips can be identified readily on the screen, the X-pulse is followed closely by a "ghost," resulting in a double vertical deflection.

The two readings given by the revolution counters are plotted on loran charts and enable the operator to determine his location.

THE RECEIVER

The AN/APN-70 receiver assembly is composed of three major units: the RF RECEIVER, the TIMER, and the DEFLECTION units. These sections are shown in block diagram form in figure 11-7, which also includes the components of the loran indicator.

RF Receiver Unit

This portion of the loran receiver is a superheterodyne system, which contains an RF amplifier, a converter, two IF amplifiers, a detector, and a video amplifier. Loran signals are received from the antenna coupler by the RF amplifier, a tuned-grid, tuned-plate circuit. The output of the amplifier is applied to the converter stage.

One section of the converter stage is used as a crystal oscillator circuit that produces mixing voltages. The IF output of the converter is amplified in the two IF amplifiers and fed to the detector. The resulting video pulses pass through one stage of amplification and are coupled through a cathode follower in the deflection unit to the video section of the indicator for subsequent application to the vertical deflection system of the cathode-ray tube.

The Timer Unit

This unit generates a series of pulses serving as the time base of the equipment and produces the variable delay intervals used to measure the time differences of the loran pulses. Also, to insure that the receiving set and the transmitter system are operating at the same recurrence rate, the timer contains circuits for synchronizing the two.

The timing standard in the receiver is an 80-kilocycle crystal oscillator from which is

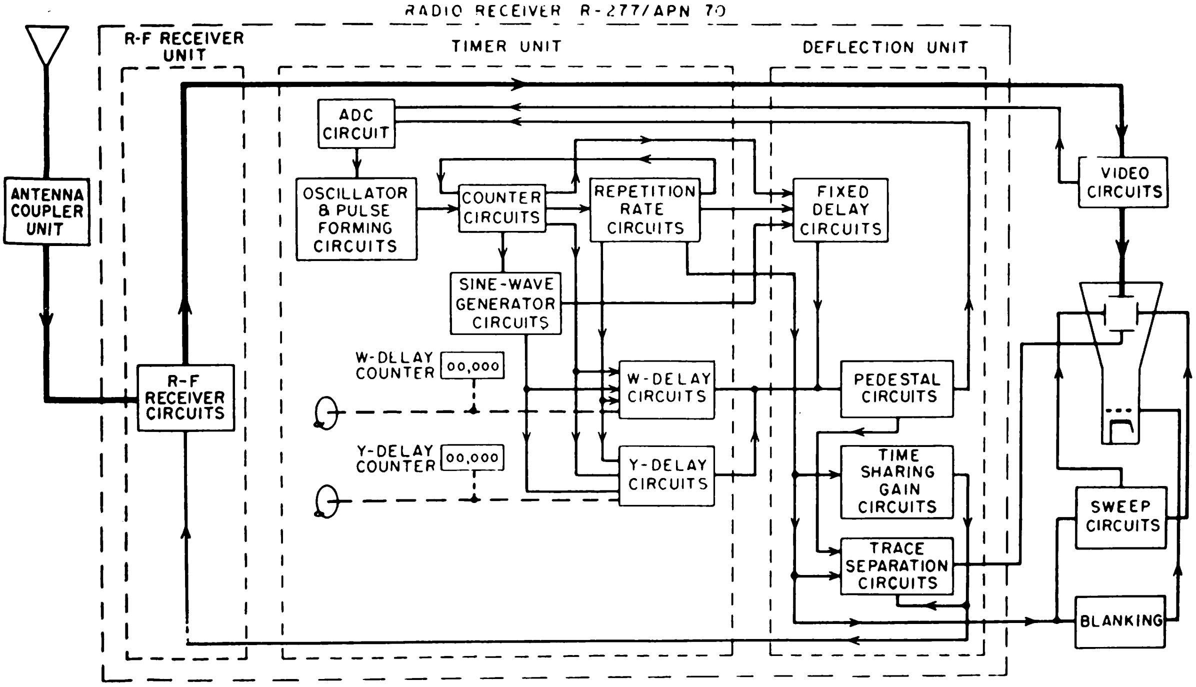


Figure 11-7.—Block diagram of the AN/APN-70 receiver.

derived (either directly or indirectly) the time bases for the timer, delay, and deflection circuits. The oscillator is synchronized with the time base of the loran transmitter by the action of the AUTOMATIC DRIFT CONTROL (ADC) circuits. The oscillator can be changed in frequency over a narrow range by a reactance tube whose d-c input grid voltage assumes a value corresponding to the degree of synchronism of the receiver circuits with the incoming loran pulses. The grid voltage of the reactance tube is produced by a discriminator tube which compares the repetition rate of the incoming master and slave pulses with the master and delay pulses from the receiver-indicator (which have a pulse rate set by the timer). Any variation in the two rates produces a d-c bias on the control grid of the reactance tube which in turn corrects the oscillator frequency and the resulting pulse rate derived from it. Thus, automatic drift control is established.

The sine-wave output of the crystal oscillator is shaped to produce a sharp negative driving pulse which is applied to the COUNTER circuits. The electronic counter contains 12 identical multivibrators and ten identical interstage amplifiers. Each counter stage is a binary (divides the input pulse rate by two). The first 11 of these stages, together with the 10 interstage amplifiers, are used to obtain the repetition rate. The 12th stage is driven by the output of the repetition rate circuits to obtain a square wave which is applied to the TRACE SEPARATION circuits through a 1,625-microsecond delay and the pedestal generator section.

The first multivibrator of the counting series is triggered by 80-kilocycle pulses derived from the PULSE FORMING circuits. The output of the first stage is fed to the grid of the first interstage amplifier tube which drives the second multivibrator. This sequence is repeated throughout the first 11 stages so that the overall division ratio is 2,047 to 1; hence, the counter chain gives one output pulse for every 2,047 pulses fed into it, when all 11 counters are used.

The REPETITION RATE circuits accept the output of the counter section and produce the reset pulses which determine the time at which the counter stages reach the count selected by the position of the recurrence rate switch. At that time a pulse is generated to reset the counter chain for the next cycle and to drive the 12th stage. The position of the recurrence rate switch may be set for any one of the 24 loran repetition rates. In addition, the repetition rate circuits supply trigger pulses to the FIXED-DELAY circuits, the TIME-SHARING GAIN circuits, and to the SWEEP circuits in the indicator unit.

The W- and Y-DELAY indicating systems consist of dials, switches, gear trains, gating tubes, wave shapers, goniometers, pulse formers, and thyratrons. These systems are connected to stages three to twelve of the binary counter chain. Each delay system produces one output pulse during each L period, and the occurrence of this output can be varied uniformly and continuously through the range zero to L/2 by means of a handcrank. Two dials indicate the microseconds of delay produced at the thyratron of each system. The W and Y systems are identical in construction and operation except that their outputs appear in successive L/2 periods for operation with LF loran signals (dual presentation). With high-frequency (single presentation) loran reception, only one delay system operates, as determined by the setting of the W-Y switch.

The Deflection Unit

In addition to the low-voltage power supply, the deflection chassis contains circuits that receive signals from the timer unit. These signals are used to synchronize and trigger waveforms that perform the following functions:

1. Generate three independent bias voltages for the three TIME-SHARING GAIN circuits.
2. Generate waveforms to drive the sweep generator in each position of the FUNCTION switch.
3. Generate trace-separation waveforms when required by the function selected at the control panel.

In single presentation, the TIME-SHARING GAIN CONTROLS enable the operator to adjust the receiver gain to an independent level on each trace appearing on the indicator screen. Either the W- or the Y-delay system may be independently selected by a control switch. Thus the delay reading and the gain setting of one pair of loran stations may remain on one counter dial and gain control knob while the operator is matching a second pair of loran pulses using the second delay system. The output of the time-sharing gain circuits also supplies bias to the RF and IF stages of the RF receiver unit.

The TRACE-SEPARATION circuits are connected to the lower vertical deflection plate of the cathode-ray tube to apply the pedestals from the PEDESTAL GENERATOR. The FIXED-DELAY stage provides a 1,625-microsecond delay for the trigger governing the appearance of the master pedestal. For dual presentation, one trigger signal for every L/2 interval is provided; while in single presentation, only one trigger signal for every alternate L/2 is required.

The PEDESTAL CIRCUITS receive pulses from the fixed-delay and variable-delay circuits and generate waveforms to produce the master and slave pedestals. The output waveforms are supplied by a cathode-coupled, one-shot multivibrator which provides a square wave of approximately 500 microseconds for the fast sweeps in single and dual operation and 1,200 microseconds for the slow and medium sweeps in single operation or 1,750 in dual operation. In position 1 of the FUNCTION switch, the multivibrator generates the pedestals seen on the traces on the indicator tube. In other positions of the switch, the pedestals are used to generate the traces, and only the video signals present during the portion of the pedestal covered by the trace are shown on the indicator tube.

THE LORAN INDICATOR

As shown in figure 11-7, the loran indicator contains the sweep circuits for developing the horizontal deflection voltages applied to the cathode-ray tube blanking circuits, the video circuits, and the cathode-ray tube. In addition, the assembly contains two high-voltage rectifiers which supply d-c potentials for the CR tube.

The sweep and blanking circuits are triggered by the reset pulses from the repetition rate circuits on function 1 and by the pedestal generator circuits on functions 2, 3, 4 and 5. A horizontal sweep generator supplies a sawtooth wave that is applied to the left horizontal deflection plate of the CR tube. A portion of the output is also fed to a phase inverter stage to give an output wave 180 degrees out of phase with the sweep generator output and which is applied to the right deflection plate, thus providing two voltages for push-pull horizontal deflection.

The blanking circuit extinguishes the electron beam in the indicator tube during retrace intervals in which the grid in the indicator tube is driven highly negative with respect to the cathode. A d-c restorer diode clamps positive swings of the CR grid to the voltage set by the BRILLIANCE control and establishes the level about which blanking takes place. An RC combination in the blanking circuit insures that the traces seen on the screen of the indicator tube are delayed until after the start of the sweep to remove irregularities in the initial parts of the sweep cycle.

Video signals derived from the RF receiver unit are amplified in the video circuits and are applied to the upper vertical deflection plate of the cathode-ray tube. A 300-kilocycle trap in the cathode circuit of the last video amplifier is provided as a low-frequency IF filter.

The d-c voltages needed for operation of the cathode-ray tube are supplied by low-voltage, regulated power supplies in the reciever unit and by the two high-voltage rectifiers in the indicator assembly. One high-voltage rectifier produces a d-c potential of 1,300 volts, positive with respect to ground, which is applied to the indicator tube through a cap connection. The other high-voltage supply develops 1,300 volts, negative with respect to ground, and is applied to the cathode of the tube through a potentiometer used as the FOCUS control.

Automatic Radio Direction Finders

Radio direction finders are radio receiving systems, used to determine the direction of arrival of a recieved radio signal. Before the development of radar and loran, radio direction finding was practically the only means by which aircraft or surface vessels could find their positions during bad weather. When an aircraft is 100 or 200 miles from a radio station, radio direction finders permit bearings to be taken from the aircraft, and the aircraft's position to be determined within a few miles. When the aircraft is close to a radio station, bearings may be taken with an accuracy that permits the aircraft to make an instrument approach to a landing field.

An automatic radio direction finder consists essentially of: (1) a radio receiver; (2) a directional-antenna system; (3) a device that indicates the direction in which the antenna is pointed; and (4) a control section to control the rotation of the antenna.

Early radio direction finders were operated manually by turning the antenna until a minimum (null) was reached in the output. Speeds attained by today's aircraft make the manually operated direction finders obsolete. Automatic direction finders (ADF's) receive a signal and automatically supply information that enables the pilot to home on that signal. Some ADF's supply additional information as to distance, longitude, and latitude.

ANTENNAS

Such terms as antenna switching, null, phase angle, and servo systems are used in the discussion of direction finders. These are explained as follows:

1. Antenna switching is a method of electronically switching a synchronous switching system antenna end-for-end. Instead of manually turning the antenna as was done with early type direction finders, it is turned electronically. A vibrator alternately connects first one end of the antenna and then the other end to the receiver input, effectively switching ends of the antenna and causing a double antenna pattern.
2. Signal null is a condition that exists when a signal induces equal voltage in both sides of a loop antenna, but in opposite directions. The result is that the signals cancel each other and little or no signal is heard.
3. Phase angle is the relationship between two voltages or currents—lag or lead—and is the principle upon which ADF's work. The signal from a loop antenna and a sense antenna will be applied simultaneously to some stage of the receiver. The action of that stage will be determined by the phase relationship between the two signal voltages.
4. Servo systems, as applied to ADF's, are the servo generators and motors that position the antenna and cause the remote indicators to indicate antenna position.

Loop Antenna

In a loop antenna, more current will flow in the side of the antenna that is turned in the direction of the transmitting station. When the antenna is turned so that it is broadside to the signal, there is equal current in the sides. These currents flow in different directions and cancel each other. This is a null position.

Sense Antenna

A sense antenna is a conventional antenna. It is called a sense antenna when used with direction finders. A vertical wire, or monopole is the simplest type of antenna. When a vertically polarized radio wave (all ground radio waves are vertically polarized) induces voltage in a monopole, the induced voltage is in phase with the incident wave, and is the same for all horizontal angles of incidence. The incident wave is the wave that induces the voltage in an antenna.

Signal Comparison

In direction finer operation of the sense-loop type system the sense antenna signal current is compared in the receiver with the signal current from the loop antenna (phase comparison). When an improper phase difference exists, the receiver causes a servo system to rotate the loop to a null position. Remote indicators attached to the loop servo system will then indicate the direction from which the signal is being received.

Loop rotation and remote indicator action are performed automatically. The pilot needs only to tune the receiver to a station and the ADF automatically presents the directional information. The receiver can also be used as a conventional receiver without ADF action.

AN/ARN-41A DIRECTION FINDER

Radio Receiving Set AN/ARN-41A is a combination automatic direction finder and radio receiver designed for use in aircraft. The major units are shown in figure 11-8. Figure 11-9 shows the interconnection of the units. When signals from the sense antenna alone are selected, the equipment functions as a conventional radio receiver for continuous wave and amplitude modulated signals. When signals are selected both from the loop and sense antenna, the equipment functions as an automatic direction finder (ADF), providing automatic visual and aural indication of the relative direction from which radio signals are being received. The equipment frequency range is from 190 through 430 kc. and from 480 through 1,725 kc. This is covered in three bands. The equipment may be used as an ADF or audio receiver on all its bands.

Figure 11-10 shows two types of indicators that are used with the ADF equipment. The indicator shown at (A) has a needle and an azimuth scale which can be manually rotated. The VAR knob located on the lower left of the instrument case is used to manually rotate the azimuth scale. When the zero degree mark of

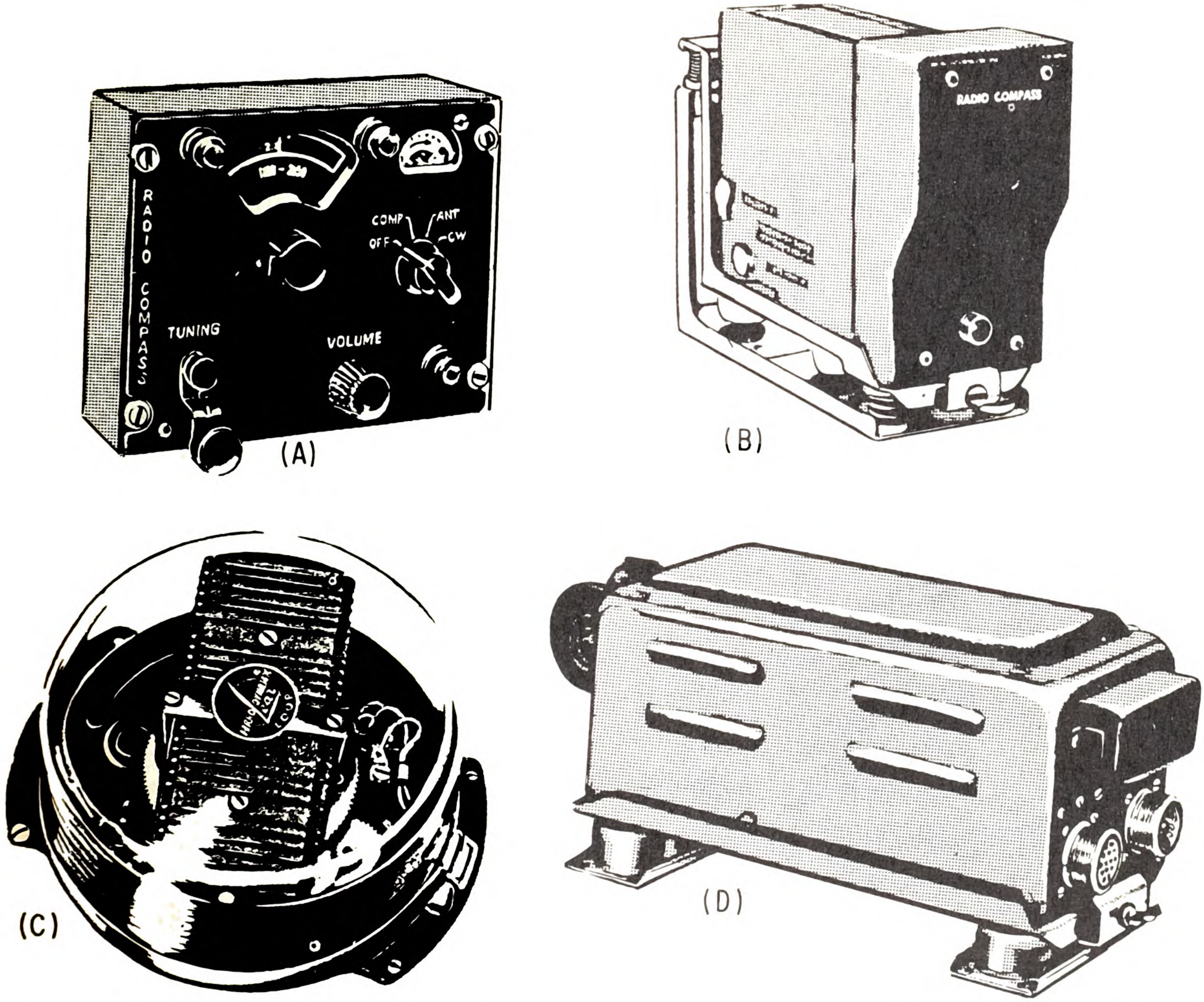


Figure 11-8.—Major units of AN/ARN-41A. (A) Set control, (B) receiver, (C) antenna, (D) electronic control amplifier.

the azimuth scale is alined with the instrument case fiducial mark (triangle at top of case), the needle indicates the direction from which signals are being received relative to the heading of the aircraft (relative bearing) during ADF operation. ADF relative bearings can be related to magnetic heading at the pilot's option by rotation of the azimuth scale with the VAR control. Rotating the azimuth scale until the reading equivalent to the aircraft's magnetic heading is under the instrument's fiducial mark, enables the pilot to read directly the magnetic bearing of the transmitting station.

The indicator shown in figure 11-10 (B) has two needles. The No. 1 needle is used for ADF and the No. 2 needle is used for VHF and UHF operation. The indicator azimuth scale is slaved to the aircraft's compass system and will rotate an amount determined by the compass. The aircraft's heading is read below the indicator case fiducial mark. The ADF magnetic bearing is indicated on the azimuth scale by the No. 1 needle. Should the compass system fail, ADF relative bearings can be estimated by using the No. 1 needle and the 45-degree marks of the instrument case.

The ARN-41A can be used for homing on a single station, for triangulation position fixing using two or more stations, or for position fixing on a single station by using any of the double bearing methods presently in use. Only ground waves of the transmitting station are used in ADF operation.

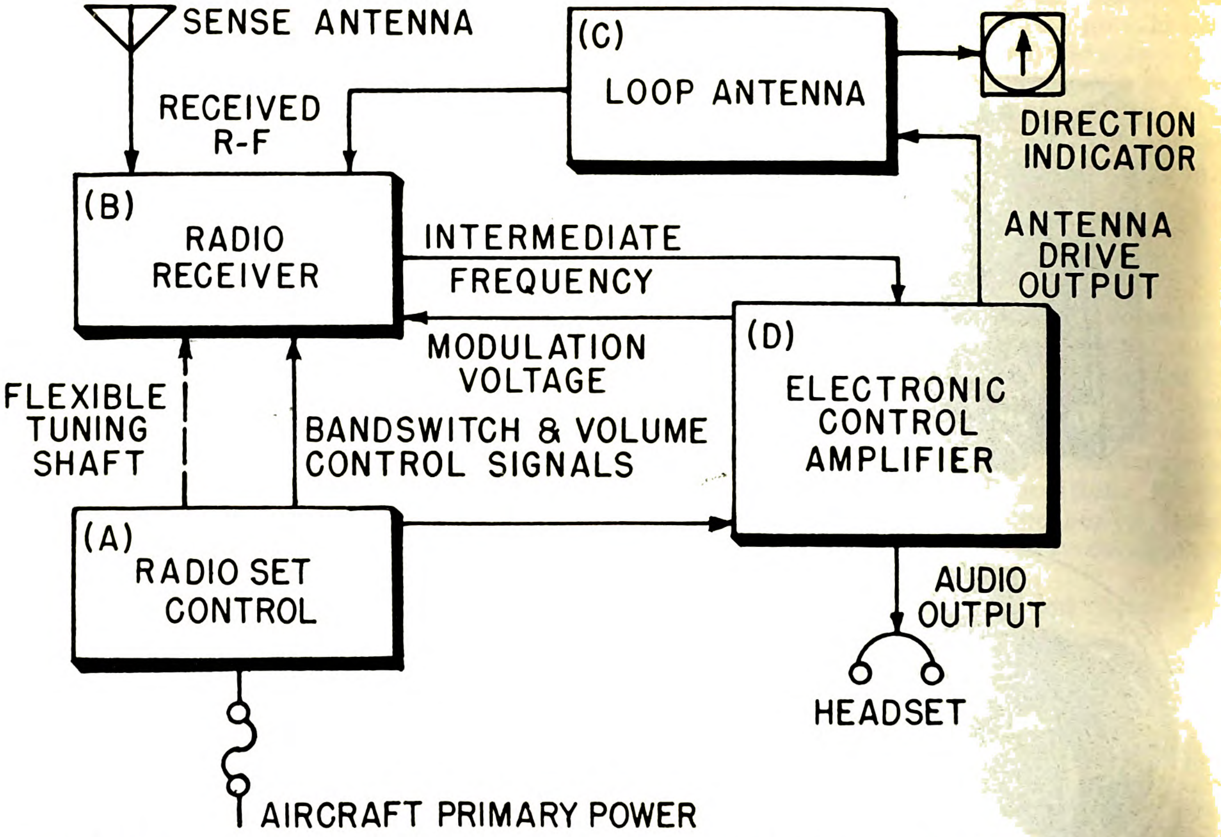


Figure 11-9.—Interconnection of AN/ARN-41A components. The letters for major units correspond to those in figure 11-8.

Radio Wave

When a radio wave leaves a vertical antenna, the field pattern of the wave resembles a huge doughnut lying on the ground with the antenna in a hole at the center. Part of the wave moves outward in contact with the ground to form the ground wave, sometimes called surface wave, and the rest of the wave moves upward and outward to form the sky wave.

Ground Wave

The ground wave moves or glides over the surface of the earth in the manner illustrated in figure 11-11. The vertically polarized wave has a vertical electrical (E) field and a horizontal magnetic (H) field. The moving electric E field creates a magnetic H field and conversely a moving H field creates an E field. The created field (either electric or magnetic) at any instant is in phase in time with its parent field, but is perpendicular to it in space.

The electric (E) and magnetic (H) fields are perpendicular to each other and perpendicular to the radio wave direction of motion through space. A right-hand rule may be applied that relates the propagation. This rule states that if the thumb, forefinger and middle finger of the right hand are extended so that they are mutually perpendicular, the thumb will point in the direction of the electric field, and the forefinger in the direction of the magnetic field if the middle finger points in the direction of the propagation.

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to be cut by lines of flux, the conductor must be perpendicular to the lines of flux, and the relative motion between flux and conductor must have a component in a direction that is perpendicular to both the lines of flux and the conductor. Therefore, the ground wave induces voltage in vertical conductors only.

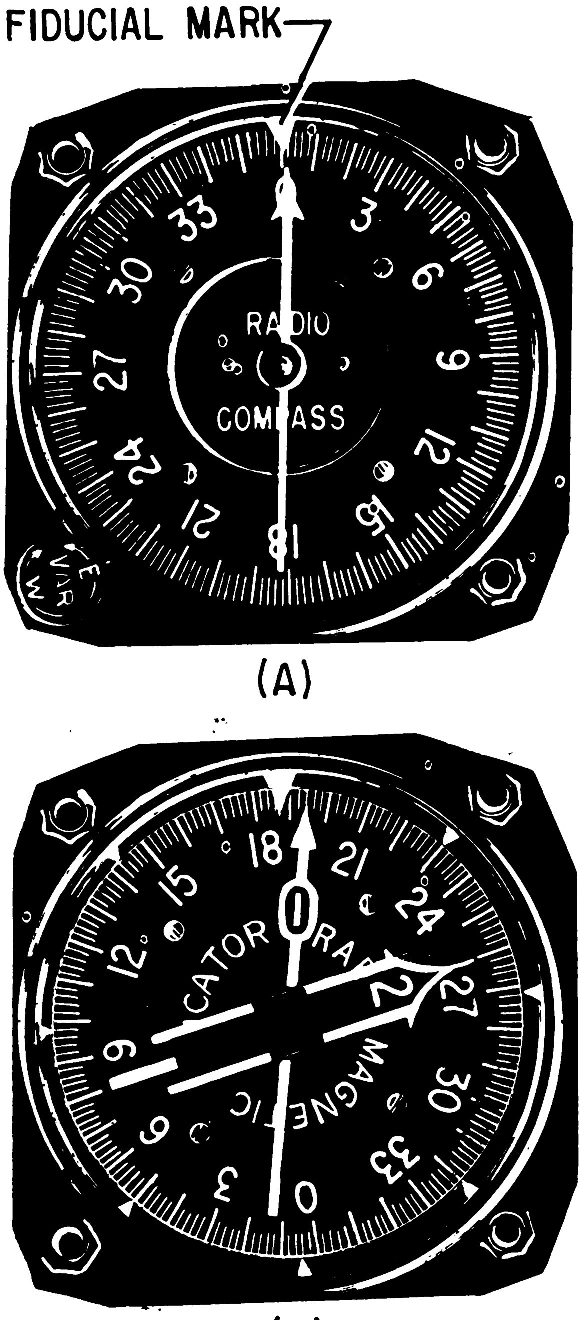


Figure 11-10.—Indicators.

ARN-41A Loop Antenna

The AN/ARN-41A loop antenna is arranged so that the loop plane is rotatable about a vertical axis, making it a vertically polarized loop antenna.

The response of the loop antenna is different from that of the sense antenna. A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incident radiation field is shown in figure 11-12 (A). As the loop is rotated about the axis XX', angle θ between the plane of the loop and the direction of the propagation of the wave is changed.

If the loop is placed in a radiation field like the one shown in figure 11-13, the H vectors of the field cut the vertical sides, AB and CD, at slightly different times. At any instant, therefore, the voltage in arm AB is slightly different from the voltage induced in arm CD. The horizontal sides BC and AD are not affected by the H lines of a wave polarized at right angles to them and do not contribute to the induced voltage in the loop.

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\theta = 90$ degrees—the vertical sides AB and CD are cut by the H vector at the same instant. The voltages induced in arms AB and CD are then the same amplitude and phase and neutralize each other, so that no current flows in the antenna loop.

Since the magnetic field of the radio wave alternates at the frequency of the wave, the instantaneous flux density at any point along the path of arrival varies sinusoidally, as shown in figure 11-13 (A). The vertical arrows represent the flux density of magnetic field strength of the incident wave. As the magnetic field at the loop changes in phase, the flux density at the loop changes as shown at $L1$, $L2$, $L3$, $L4$, and $L5$, which are top views of the loop at various phases of the incident wave. The loop is stationary and the wave moves, but in the figure the loop is shown at five positions along a stationary wave. The loop is seen from the top, and the voltages are induced by the magnetic flux lines cutting the vertical sides of the loop, which are in a plane perpendicular to the page.

When the phase of the incoming wave is 0 degrees, the loop is at position $L1$, with respect to the wave, and the lines of flux cutting the vertical sides of the loop are of opposite polarity. The voltages induced in the two sides are then in opposite directions, and maximum voltage is developed in one direction around the loop. When the phase is 180 degrees, the loop is at position $L4$, and again the induced loop voltage is a maximum, but is in the opposite direction to that of $L1$. When the phase is 90 and 270 degrees (loop positions $L3$ and $L5$)

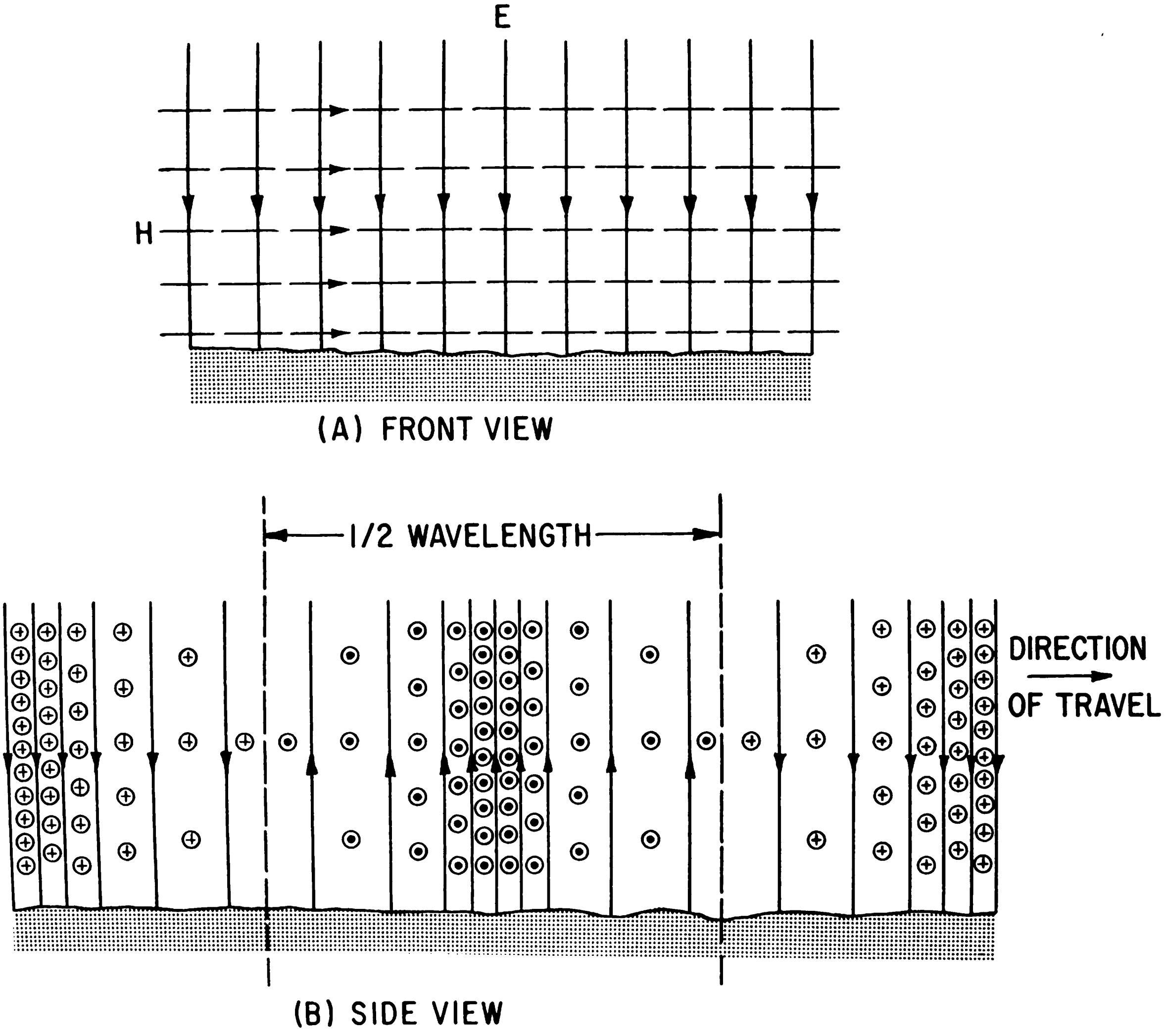


Figure 11-11.–Front and side views of a ground wave. The solid lines represent electric field (E) while the dotted lines and circles indicate magnetic flux (H).

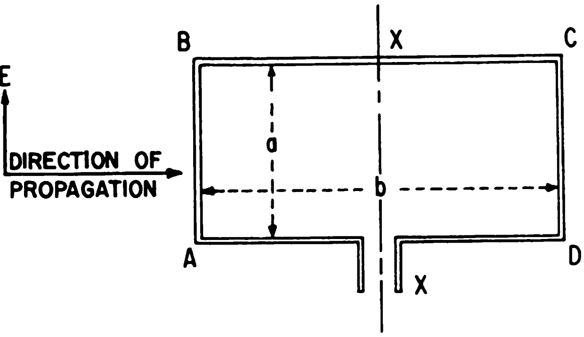
the instantaneous flux cutting each of the sidearms is the same in magnitude and direction, so that the resultant loop voltage is zero.

The induced loop voltage is shown in figure 11-13 (B) for a single cycle of the incident wave. A comparison of (A) and (B) in figure 11-13 shows that the induced loop voltage differs in phase from the incident wave by 90 degrees, and leads or lags the incident wave according to which edge of the loop is nearer the signal source.

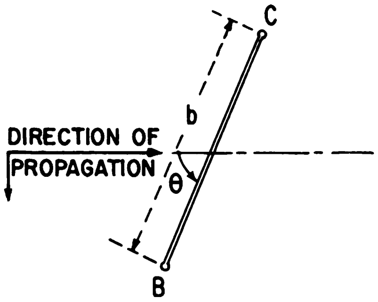
The induced voltage of the loop antenna is not in phase with the incident wave. It will lead or lag the incident wave by 90 degrees and the magnitude of the induced voltage will depend on the position of the loop plane with respect to the direction of wave travel. The voltage will be minimum when the loop plane is perpendicular to the direction of wave travel, and maximum when the loop plane is parallel to the direction of wave travel.

Conventional AM Receiver Operations

Whether the equipment will operate as a conventional receiver or as an ADF depends on the setting of the function switch on the front panel of the set control. When the function switch is turned to ANT, the ADF circuits are disconnected and the equipment operates as a



SIDE VIEW
(A)



TOP VIEW
(B)

Figure 11-12.—Loop antenna in radiation field. (A) Side view; (B) top view.

conventional receiver. Figure 11-14 is a block diagram of the AN/ARN-41A. The sense antenna alone is used. The sense antenna signal is amplified and then inductively coupled to *V*4. This stage acts as both oscillator and mixer. The RF voltage from *V*3 is coupled to the oscillator voltage by the common electron stream converting the signal to a 455 kilocycle IF. The signal then is inductively coupled to *V*101, the first amplifier, by use of an IF link coupling system. The IF link system provides a transfer of the IF signal developed in the radio receiver to the IF amplifiers located on the control amplifier. IF amplifier *V*101 is inductively coupled to the second amplifier *V*102. Detection of the IF signal and rectification are accomplished by the two sections of *V*103, a duodiode triode. The triode section of the tube acts as a first audio amplifier. The audio signal path from the first audio amplifier to the

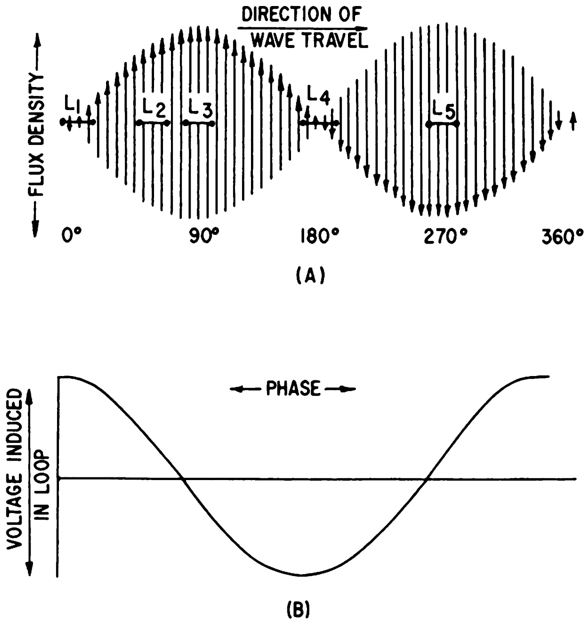


Figure 11-13.—Induction of an alternating voltage in a loop antenna. (A) Top view of loop at various phases of incident wave; (B) one cycle of induced loop voltage.

second audio amplifier *V*107A has the desired effect of limiting the low frequency response of the audio amplifier, thus, reducing the 115 cycles per second hum in the headset when the equipment is on ADF operation. *V*107A is used to directly drive *V*106 which forms half of the push-pull audio output stage.

A voltage divider network splits off some audio for the grid of *V*107B, the phase inverter. *V*107B amplifies its portion so that *V*105 is driven with a voltage equal in magnitude but opposite in phase to the driven voltage of *V*106, thus driving the output stage in the proper manner. The audio power output stage is a conventional push-pull circuit using two tubes, *V*105 and *V*106. The output from the audio power output stage is transformer coupled to the headset.

When the function switch *S*202B on the set control is turned to CW, the cathode circuit of the beat frequency oscillator is completed to ground through *S*202B contacts 4 and 1. The BFO permits manual tuning of the equipment to CW signals.

ADF Operation

When the function switch, *S*202B, on the set control is turned to COMP position, the common

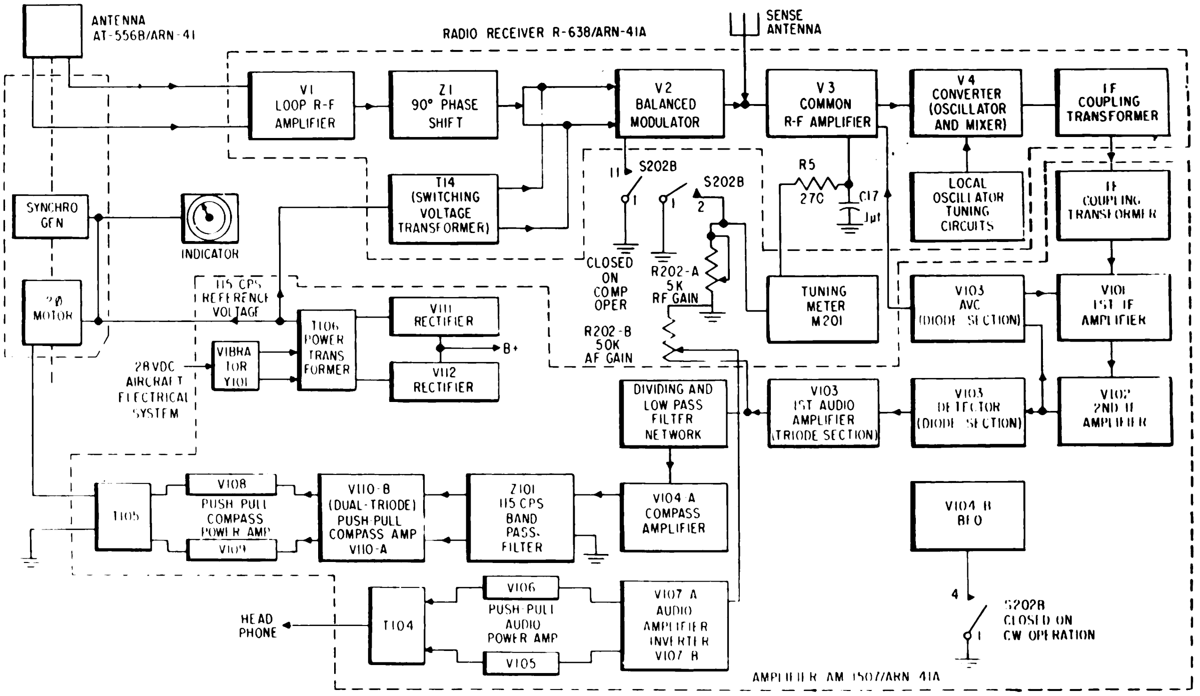

ANTENNA AT-556B/ARN-41
RADIO RECEIVER R-638/ARN-41A
SENSE ANTENNA
V1 LOOP R-F AMPLIFIER
Z1 90° PHASE SHIFT
V2 BALANCED MODULATOR
V3 COMMON R-F AMPLIFIER
V4 CONVERTER (OSCILLATOR AND MIXER)
IF COUPLING TRANSFORMER
T14 (SWITCHING VOLTAGE TRANSFORMER)
S202B
11
1
2
CLOSED ON COMP OPER
R202-A 5K RF GAIN
R202-B 50K AF GAIN
R5 270
C17 1µf
LOCAL OSCILLATOR TUNING CIRCUITS
IF COUPLING TRANSFORMER
SYNCHRO GEN
INDICATOR
2Ø MOTOR
115 CPS REFERENCE VOLTAGE
T106 POWER TRANS FORMER
V111 RECTIFIER
V112 RECTIFIER
B+
VIBRATOR Y101
28 VDC AIRCRAFT ELECTRICAL SYSTEM
TUNING METER M201
V103 AVC (DIODE SECTION)
V101 1ST IF AMPLIFIER
DIVIDING AND LOW PASS FILTER NETWORK
V103 1ST AUDIO AMPLIFIER (TRIODE SECTION)
V103 DETECTOR (DIODE SECTION)
V102 2ND IF AMPLIFIER
T105
V108
PUSH PULL COMPASS POWER AMP
V109
V110-B (DUAL-TRIODE) PUSH-PULL COMPASS AMP V110-A
Z101 115 CPS BAND PASS. FILTER
V104-A COMPASS AMPLIFIER
V104-B BFO
4
S202B CLOSED ON CW OPERATION
HEAD PHONE
T104
V106
PUSH-PULL AUDIO POWER AMP
V105
V107 A AUDIO AMPLIFIER INVERTER V107 B
AMPLIFIER AM 1507/ARN 41A

Figure 11-14.–Radio set AN/ARN-41A, block diagram.

cathode of the balanced modulator is grounded through *S*202B contacts 11 and 1 and the RF potentiometer R202A is shorted through *S*202B contacts 2 and 1. Thus the ADF circuits are in operation and the equipment operates as an ADF. Now the loop antenna signal can be used by the equipment.

It has been mentioned that the loop antenna signal leads or lags the sense antenna signal by 90 degrees, depending upon which edge of the loop is closer to the direction of reception; and when the plane of the loop antenna is perpendicular to the direction of propagation from the transmitting station, the loop signal is at a minimum. The loop antenna signal is RF transformer coupled to *V*1, conventional RF amplifier. The plate circuit of *V*1 is a phase shifting network, *Z*1, which is tuned below the lowest frequency present in the output of *V*1. This results in a 90 degree lag in the output of *V*1, which causes the signal delivered from *Z*1 to the balanced modulator *V*2 to be either in or 180 degrees out of phase with the signal from the sense antenna. That is, if the loop signal originally led the sense signal by 90 degrees, it is in phase with the sense signal after being delayed 90 degrees by *Z*1; on the other hand if the loop signal lagged the sense signal 90 degrees, it is now 180 degrees out of phase with the sense signal. In either case, the *Z* output is coupled simultaneously to the tw halves of *V*2, the balanced modulator.

The loop antenna is driven by a two-phas motor. This motor has two windings, a fixe and variable phase winding. The fixed phas winding of the motor is constantly excited at frequency of 115 cycles. The output signa (115 cycles) from the compass power amplifie provides the excitation applied to the variabl phase winding of the two-phase motor.

Excitation of the variable phase must eithe lead or lag that in the fixed phase 90 electric degrees for motor torque to result in on direction or the other. The direction of rotatio of the motor depends on the lag-lead relation ship of the 90 degree out-of-phase excitati placed across the variable phase winding.

In this equipment the power supply vibrato *Y*101 supplies the reference voltage to the fixe phase loop antenna motor winding and to th switching voltage transformer *T*14 through separate secondary winding of power trans former *T*106 and a reactor coil.

The output from the switching voltage trans former *T*14, which is a 115 c.p.s. signal degrees out of phase with the reference signa applied to the fixed phase winding of the loo antenna motor, is applied in push-pull to th

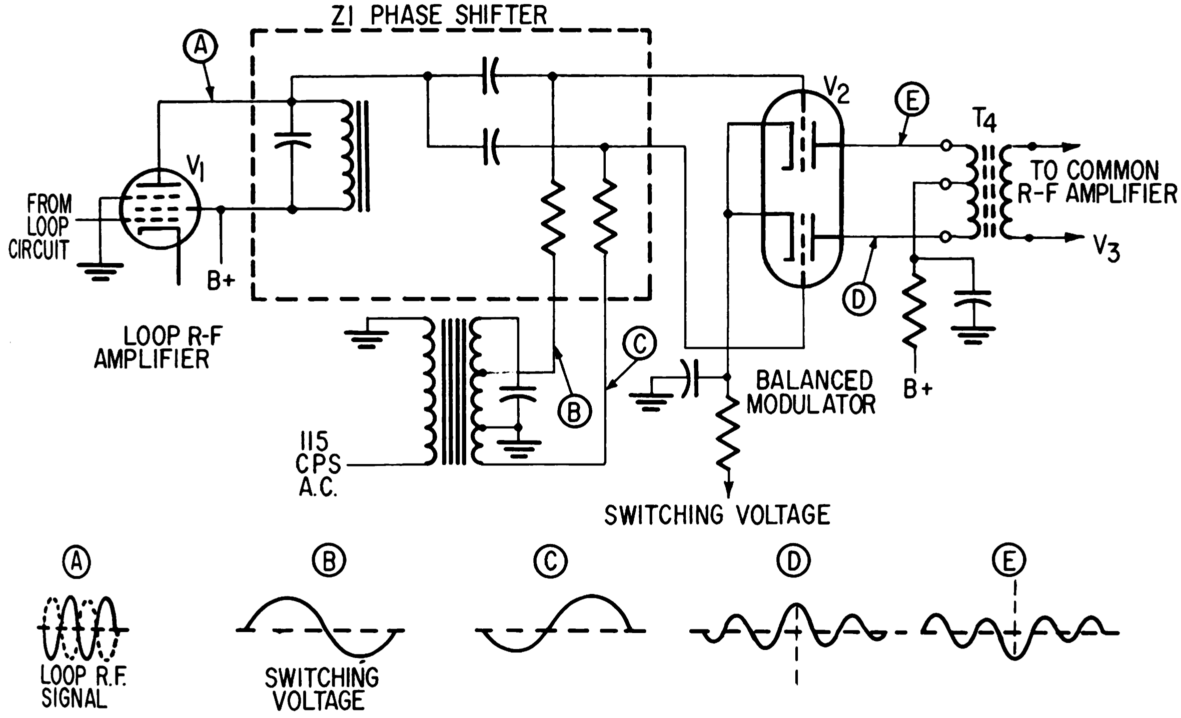


Figure 11-15.—Balanced modulator.

alanced modulator $V2$. (See fig. 11-15.) The 0 degree phase difference is necessary to nable the final output from the equipment to e variable phase winding of the loop antenna otor to be 90 degrees out of phase with the xed phase winding. Whether the signal from e ADF stage leads the fixed phase winding by 0 degrees or lags it by 90 degrees is determined by whether the loop antenna is to the left right of the null condition. The system is so nstructed that the motor is always caused to tate the loop toward the true null condition.

The $Z1$ signal (in phase or 180 degrees out phase with the sense signal) is applied to th halves of the twin triode, $V2$, balanced odulator tube in the same phase (push-push). he 115-cycle signal is applied in opposite ase (push-pull) to the two grids by means of e center-tapped secondary of transformer, 14. In the twin triode, $V2$, both halves are ased so that the halves of the tube only conct the 90 degree phase shifted loop antenna gnal, $Z1$ signal, when their grids are driven sitive by the positive half cycle of the 115-cle voltage applied to the grids, as shown in gure 11-15.

The plates of the balanced modulator $V2$ eed opposite ends of the center-tapped $T4$ transformer primary. The signal in the $T4$ transformer secondary, balanced modulator output, is therefore induced alternately 115 times a second by each half of the primary. One of the halves of the primary will produce an adding signal with respect to the sense signal. The other half will produce a subtracting signal which cancels part of the sense antenna signal. This is because the output from each half is applied to opposite ends of the center-tapped primary. The resultant signal made up of the balanced modulator output signal and sense signal is an RF signal with a 115-cycle envelope. (See fig. 11-16.) Whether the 115 c.p.s. modulation envelope leads or lags constant excitation voltage to the loop antenna motor depends upon whether the loop is right or left of null, and its magnitude depends on the amount of displacement of the loop antenna from its null.

The modulated signal is then amplified and converted to the 455 kilocycles IF frequency, which is amplified by two IF stages. This is then detected, and the audio signal is amplified. (See fig. 11-14.)

The 115 c.p.s. modulated audio signal is applied across the dividing and low-pass filter network and R 202B. The filter network provides a low impedance path to the 115 c.p.s. signal,

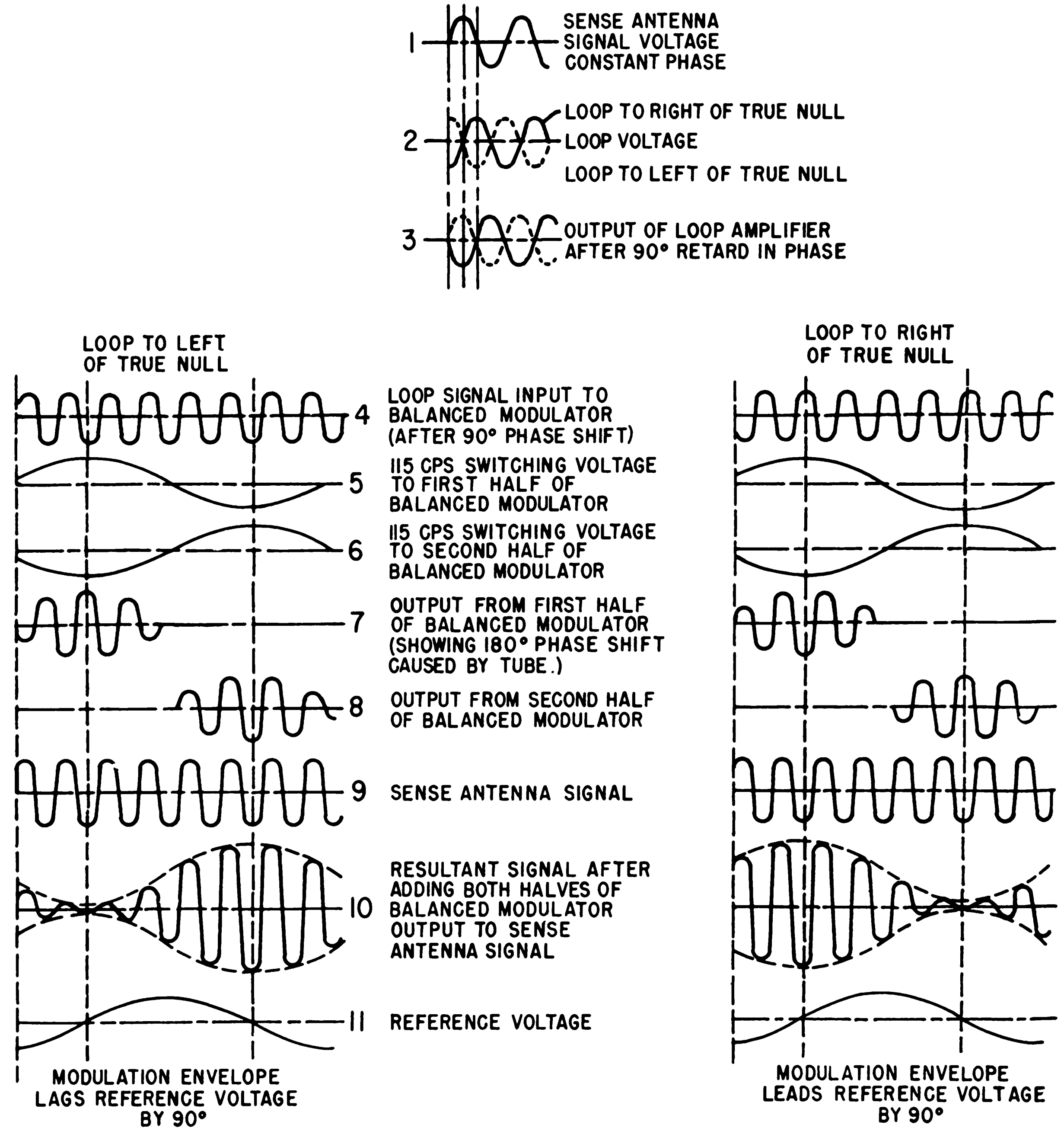

1
SENSE ANTENNA SIGNAL VOLTAGE CONSTANT PHASE
2
LOOP TO RIGHT OF TRUE NULL
LOOP VOLTAGE
LOOP TO LEFT OF TRUE NULL
3
OUTPUT OF LOOP AMPLIFIER AFTER 90° RETARD IN PHASE
LOOP TO LEFT OF TRUE NULL
LOOP TO RIGHT OF TRUE NULL
4
LOOP SIGNAL INPUT TO BALANCED MODULATOR (AFTER 90° PHASE SHIFT)
5
115 CPS SWITCHING VOLTAGE TO FIRST HALF OF BALANCED MODULATOR
6
115 CPS SWITCHING VOLTAGE TO SECOND HALF OF BALANCED MODULATOR
7
OUTPUT FROM FIRST HALF OF BALANCED MODULATOR (SHOWING 180° PHASE SHIFT CAUSED BY TUBE.)
8
OUTPUT FROM SECOND HALF OF BALANCED MODULATOR
9
SENSE ANTENNA SIGNAL
10
RESULTANT SIGNAL AFTER ADDING BOTH HALVES OF BALANCED MODULATOR OUTPUT TO SENSE ANTENNA SIGNAL
11
REFERENCE VOLTAGE
MODULATION ENVELOPE LAGS REFERENCE VOLTAGE BY 90°
MODULATION ENVELOPE LEADS REFERENCE VOLTAGE BY 90°

Figure 11-16.—Phase relationships in ADF operation.

thus the signal developed across R202B is the higher frequency audio component (present due to the signal's original modulation at the transmitter). The higher frequency audio component is delivered to the audio amplifier stage, and the 115 c.p.s. signal to the compass amplifier.

The audio amplifier provides final amplification of the signal to which the equipment is tuned.

The compass amplifier provides the variabl phase winding of the loop motor with the 90-degree lead or lag 115 c.p.s. signal. The 11 c.p.s. signal from the divider and low-pas filter network is amplified by *V*104A, a sectio of a dual triode AF voltage amplifier. Th amplified signal from *V*104A is applied to *Z* 101 a bandpass filter with a sharp cut-off above 11 c.p.s. *Z*101 also accomplishes phase inversion for *V*110, a dual triode used as a push-pull driver for the compass power output stage.

The compass output stage consists of *V*108 and *V*109, power amplifier pentodes driven in push-pull. The 115 c.p.s. output is coupled through *T*105 to the variable phase winding of the loop antenna motor. This results in a 90 degree lag or lead voltage impressed across the variable phase winding with respect to the reference voltage continually supplied to the fixed phase winding of the loop antenna motor. The direction of loop antenna movement depends on which winding is leading the other by 90 degrees.

The loop motor, when the variable phase winding is excited, rotates the antenna to a null position where there is no output from the loop antenna.

A simple synchro system is used to indicate the position of the loop antenna with respect to the heading of the aircraft. The synchro system consists of a synchro generator, sometimes called a synchro transmitter, and a synchro motor sometimes called a synchro receiver. The synchro generator rotor is directly coupled to the shaft that drives the loop antenna while the synchro motor, located in the indicator, has the indicator needle attached to its rotor. In this system, when the shaft of the synchro generator is turned, an electrical signal is generated and transmitted to the synchro motor. This signal acts on the synchro motor, causing its shaft to rotate exactly the same number of degrees as the generator shaft.

AN/ARA-25

This is an ultrahigh-frequency ADF (automatic direction finder) that is used on most naval aircraft that utilize the ARC-27 transceiver, and it is designed specifically as a complementary item for the ARC-27. (The ARC-27 is discussed in chapter 9.) Desirable performance of the ARA-25 along with few maintenance problems have proven it to be a reliable homing equipment. Accurate bearings on received signals at relative bearings of 000° and 180° are rapidly obtained, and while this is being accomplished, communication with the ARC-27 is interrupted for only very short periods of time. Bearings at other than 000° or 180° relative are not as accurate due to deviation. Figure 11-17 shows the major units of the set.

The heart of the ARA-25 ADF is the directional antenna. Because of the directional characteristics of RF energy at UHF frequencies and the design of the directional antenna,

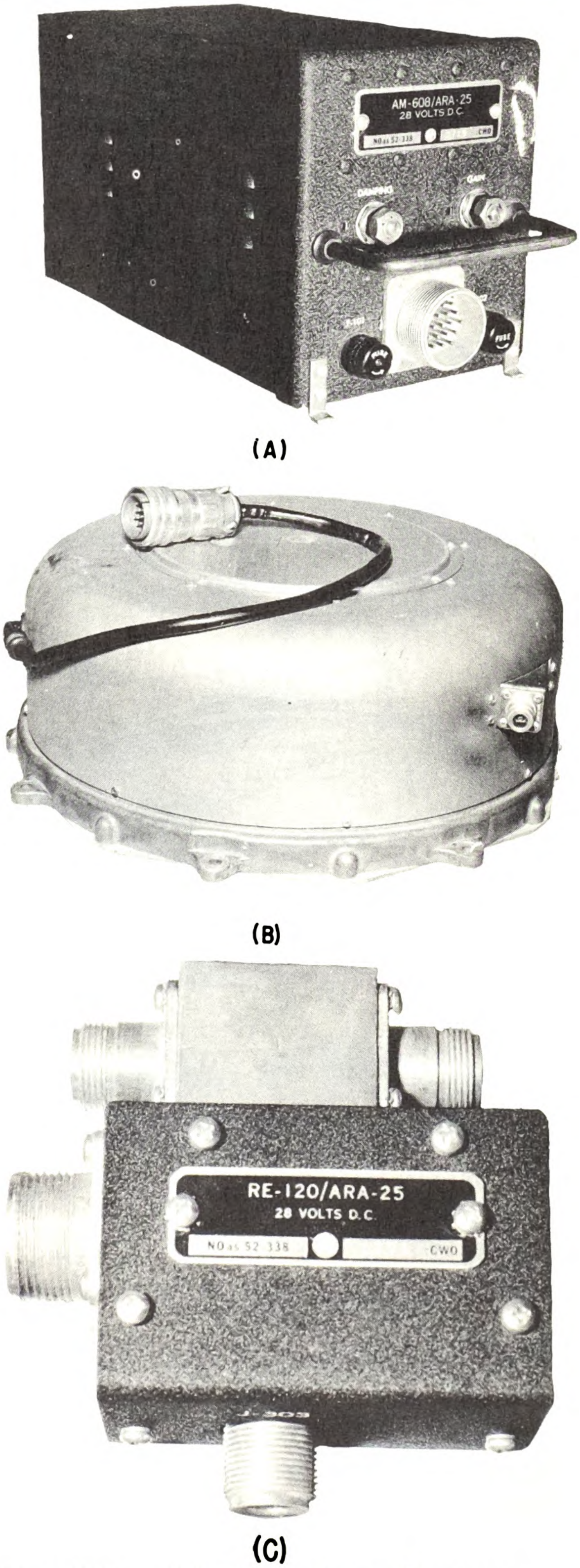


Figure 11-17.—(A) Amplifier indicator; (B) antenna assembly; (C) antenna relay.

no sense antenna is necessary. The ARA-25 antenna is a flat, diamond shaped plate placed over a tapered cavity. The cavity is designed to maintain a 50-ohm characteristic impedance at the frequency of the AN/ARC-27 (225 mc. to 400 mc.). An exploded view of the antenna assembly is shown in figure 11-18.

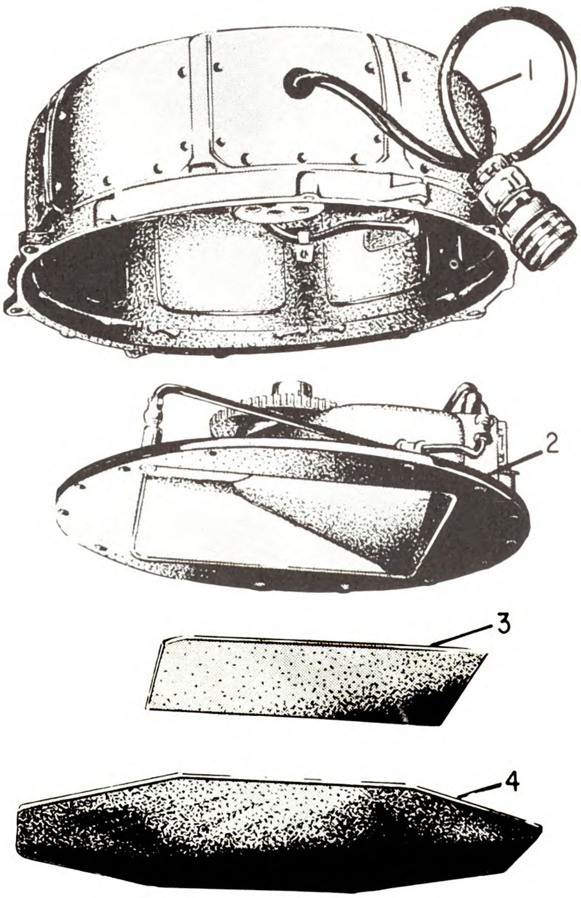


Figure 11-18.—Exploded view of antenna assembly.
1. Assembly housing and gear assembly.
2. Antenna cavity, with feeder connections.
3. Disk antenna.
4. Plastic cover plate.

Figure 11-19 shows in block diagram form how the ARA-25 works in conjunction with the ARC-27. Those units connected by dotted lines work in synchronism, and are controlled by the 100 c.p.s. vibrator. The synchronous filter is designed to remove noise, resulting in an excellent signal-to-noise ratio.

Power to the ARA-25 direction finder is controlled from the ARC-27 control box. No independent console control is available for the ARA-25, although the B+ line from the ARC-27 and the +28-volt d-c line are fused on the front panel of the ARA-25 amplifier-indicator.

With the ARC-27 switch on and the ADF switch on the ARC-27 control box in the STANDBY position, only +28-volt d-c filament power is supplied to the ARA-25 amplifier-indicator. As soon as the ADF switch is moved to the ON position, the antenna relay switches the input to the ARC-27 from the regular UHF communication antenna to the directional antenna. At this time a relay closes in the servo amplifier, furnishing B+ to the amplifier tubes, +28 volts d.c. to the 100-c.p.s. power vibrator and antenna servomotor armature. This action also changes the ARC-27 automatic volume control time constant to respond to a 100 cycle rate, and removes the AVC delay voltage. When the transmitter is keyed and the selector switch on the control box is in ADF position, the communication antenna is switched and connected to the transmitter.

The operation of the power vibrator energizes (with essentially a square wave) the switching relay, the synchronous filter relay, the rate generator excitation coil, and the antenna servomotor field switching relay. Since all of the switching relay coils are energized by the output from the power vibrator, the whole system is kept synchronized. The result of the synchronously switched filter is the greatly improved signal-to-noise ratio, mentioned previously.

Operation of the vibrator causes the antenna switching relay to switch from one end of the antenna to the other at approximately 100 c.p.s. This switching action effectively modulates the input RF (modulated or unmodulated) to the ARC-27. The output from the ARC-27 is approximately a 100-c.p.s. waveform. The amplitude for each half-cycle depends upon the amplitude of the signal pattern received on each half cycle from each end of the antenna. This antenna signal is similar to that of a loop antenna. The audio signal is fed to the amplifier in series with a signal from the rate generator, located in the antenna assembly. The rate generator produces a signal that is proportional to the rate of change of the angle (up to 180 degrees) between the directional antenna pattern true null and the relative bearing of the signal. A damping voltage is thus provided to prevent overshooting or undesired hunting of the antenna.

The composite waveform passes through one stage of amplification, and is then applied

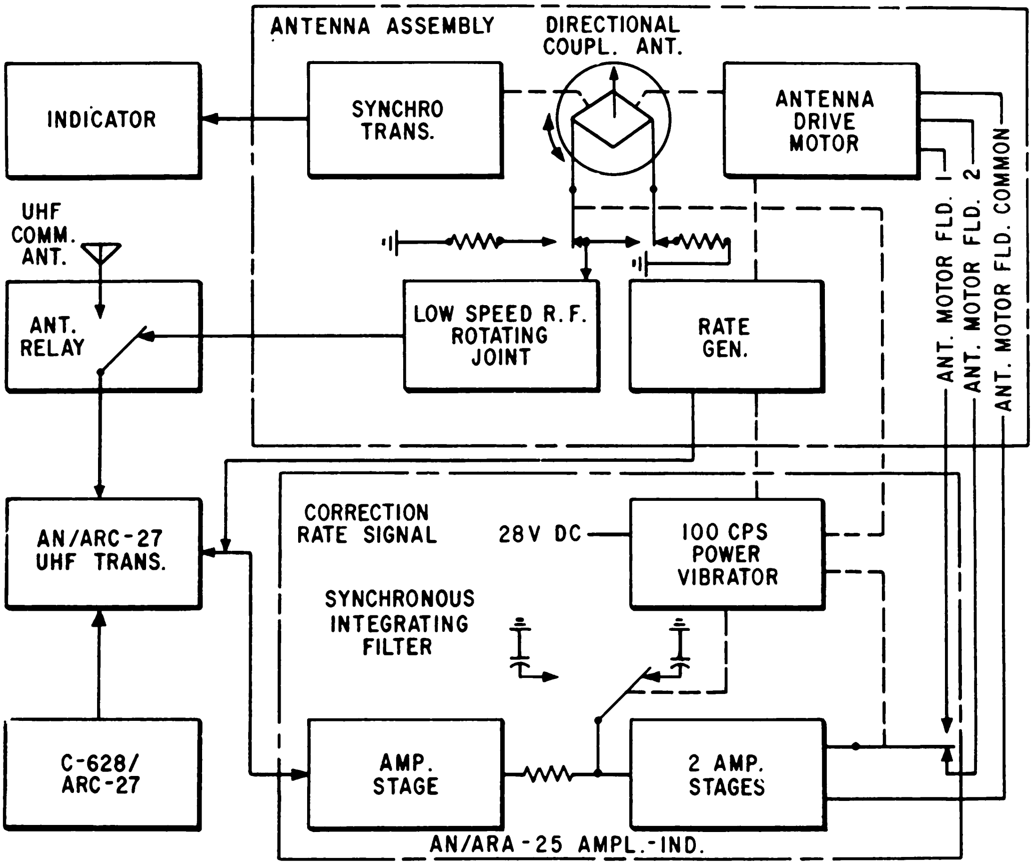


Figure 11-19.—ARA-25 functional block diagram.

to a filtering network whose two filtering capacitors are switched by the power vibrator in synchronism with the antenna switches. The synchronous switching of the capacitors causes one capacitor to charge to the average peak value of the first half-cycle of the applied waveform and the other capacitor to charge to the average peak value of the second half-cycle, thus cleaning up the harmonic hash that was previously riding the input signal. This circuit is the primary means of obtaining the desirable signal-to-noise ratio in the ARA-25.

The grounded side of the output transformer secondary is also switched by the power vibrator so that the field of the antenna servomotor receives a direct current. The direction of this current flow is dependent upon whether the station is to the left or right of the true null; its magnitude is dependent upon the difference in amplitude of the signal received on the first and second half cycle.

Since the armature of the servomotor has a constant 28 volts d.c. impressed across it through a current-limiting resistor, the motor will turn in a direction depending upon the direction of current flow in the field. The amplitude of the signal applied to the receiver on each half cycle will be equal, thus no 100 c.p.s. modulation is developed, and current flow through the field of the motor ceases. The mechanical motion of the antenna is transferred electrically to the bearing indicator by the synchro transformer, located in the ARA-25 antenna assembly.

Operation of the ARA-25 ADF is simple. All that is required is to select the ADF position on the ARC-27 control box and then tune the ARC-27 to whatever signal is desired. The desired signal may be from a control tower, a signal on the emergency frequency, another aircraft's transmission, or any signal the ARC-27 can receive.

Bearing given by the ARA-25 ADF will normally be indicated on needle No. 2 of the ID-250/ARN indicator.

Radio Ranges and Related Facilities

LOW-FREQUENCY RADIO RANGES

A radio range is a continuous-wave station, he radiation from which produces directional courses or tracks. These courses remain stationary with respect to the surface of the earth and serve to guide aircraft over long distances. The older equipment used to produce he range courses consists of low-frequency ground stations operating from about 200 to 400 kilocycles. Associated with the range stations are marker beacon stations. These are transmitters which have limited and highly directional radiation used to give the pilot nformation concerning his position along the range course.

The low-frequency range station provides four courses. The ground equipment includes wo transmitters and five antenna towers of about 130 feet in height. The antennas comprise he Adcock system; four towers are located on he corners of a square. The fifth tower is situated in the center of the square. Diagonally opposite towers are separated by a distance of about 600 feet and are operated simultaneously o constitute a pair. Each pair radiates a figure-of-eight pattern in the horizontal plane. The center tower has a radiation pattern which s nondirectional.

The two corner pairs are driven by a crystal-controlled transmitter through a relay which is operated by a motor-driven keyer. The keyer energizes the two sets of antennas alternately. One pair gives a series of dot-dash characters (letter A in code), and the other is keyed with a series of dash-dot (letter N) characters, also station identification signals are transmitted every 30 seconds. The center ower is fed by a second crystal-controlled ransmitter which develops a carrier frequency which is 1,020 cycles lower than the radiation of the other four antennas. When the combined signals are present in the receiver, a 1,020-cycle output is produced as a beat frequency rom the two types of transmissions.

The two figure-eight patterns and the nondirectional emission of the center tower produce a total space pattern as shown in figure 11-20. The signal heard in a receiver depends upon the position of the receiver with respect o the antenna system. In those positions where he A and N signals overlap, or exist in equal strength, no separate code character is heard but rather a continuous tone resulting from the interlocking code characters. The areas of overlap determine the four courses provided by the station.

In effect the center tower provides the carrier energy and the corner towers supply sideband power for producing the audible beat note and station identification signal. In addition, the center antenna is used for transmitting voice modulation, and the airborne receiver is equipped with filters so that the pilot can select voice or range signals without interaction. In those positions where the A and N signals exist in equal strength, no separate code character is heard but rather a continuous tone resulting from the interlocking of code characters. This area, or beam, is approximately 3 degrees wide and determines the four courses provided by the station. There is an area known as the bilateral or twilight zone on either side of the 3 degree-constant tone beam. In this area the predominant character exists, accompanied by a steady background tone produced by the weaker interlocking character.

RADIO MARKERS

As shown in figure 11-20, marker signals are used in conjunction with the range courses to provide for position checking along the route. Two types of marker signals are used, Z MARKERS and FAN MARKERS. The Z-marker transmitter is located at the range station and the signal gives positive identification of the cone of silence. This signal is a crystal-controlled, 75-megacycle emission modulated by a 3,000-cycle tone.

Fan markers are produced by keyed, 100-watt, 75-mc. transmitters located on or near the range course about 20 miles from the range station. The emitted signal is modulated by a 3,000-cycle tone which is keyed in dashes to identify the range leg containing the marker. Starting at north and proceeding clockwise, the dashes increase in number with the course legs. If there are two fan markers located on one leg, the outer marker signal is coded with two dots preceding the dashes.

The airborne equipment used in reception of marker signals is usually a single-frequency superheterodyne receiver which is crystal controlled. The receiver output is filtered and applied to a signal circuit which causes a lamp to glow on the instrument panel when the marker

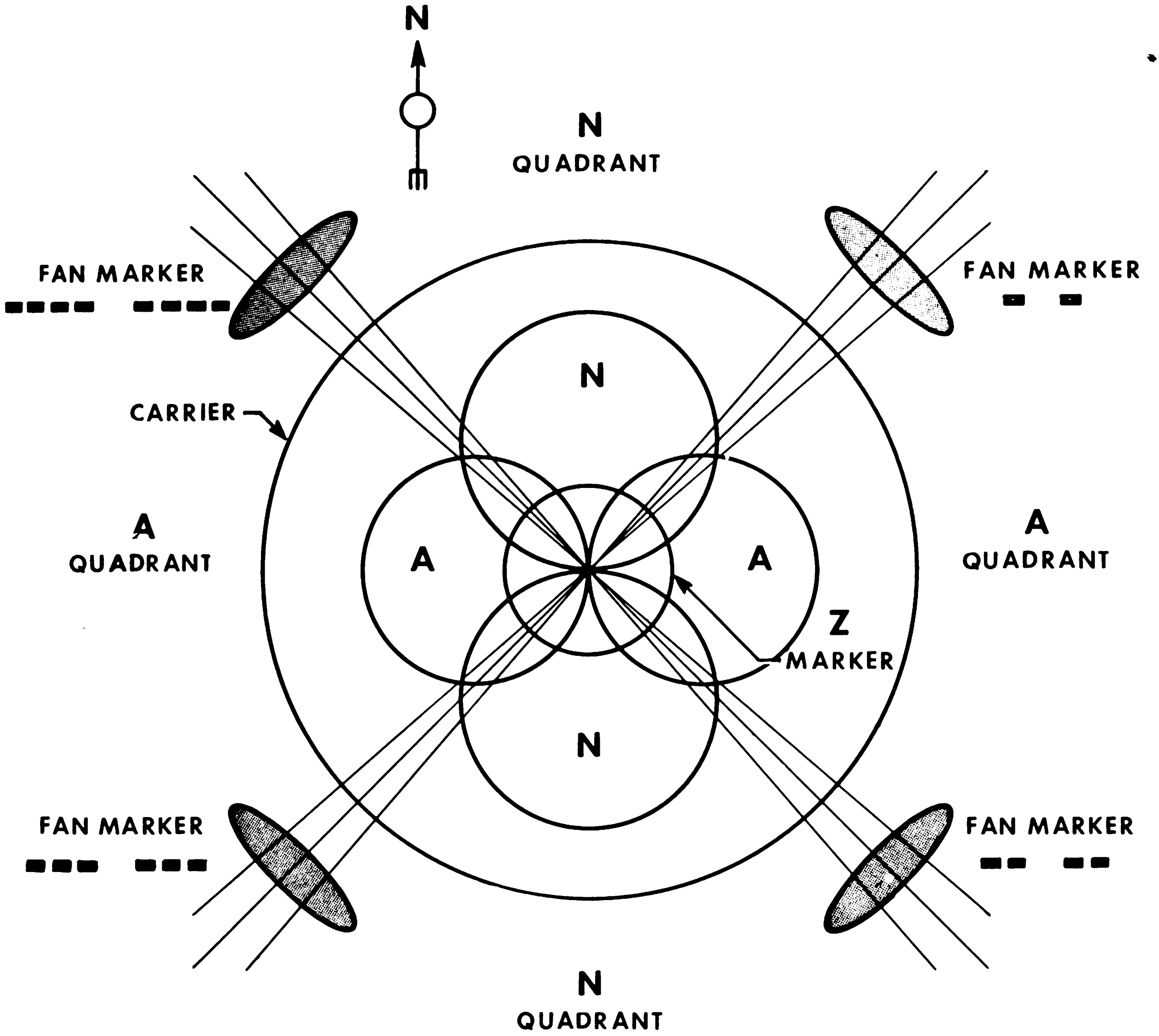


Figure 11-20.—Courses and radiation patterns of the low-frequency range.

signal is received. The tone is also applied to the pilot's phone circuit to give aural identification of the position. The marker signals are usually radiated from an antenna array consisting of four half-wave elements and a counterpoise. The cross sections of the radiation patterns produced are shown in figure 11-21.

The bone-shaped cross section of the fan marker radiation is a newer type than the standard section shown at its left. This pattern is employed to give sharper identification than is provided in the standard pattern.

VISUAL-AURAL RANGE (VAR)

The visual-aural range system is a very high-frequency facility which like the low-frequency range provides four courses. The VAR system was developed to eliminate the problems of noise and interference present in the low-frequency range and also to facilitate the identification of the range quadrants. As shown in figure 11-22, the four courses consist of two aural and two visual tracks.

The aural courses are formed in the overlapping areas of A and N signals and are radiated by the same general method employed in the low-frequency range. The antenna array contains three horizontal loops for the visual system and two additional loops for the aural signals. The center antenna serves to radiate the carrier which combines with both the aural

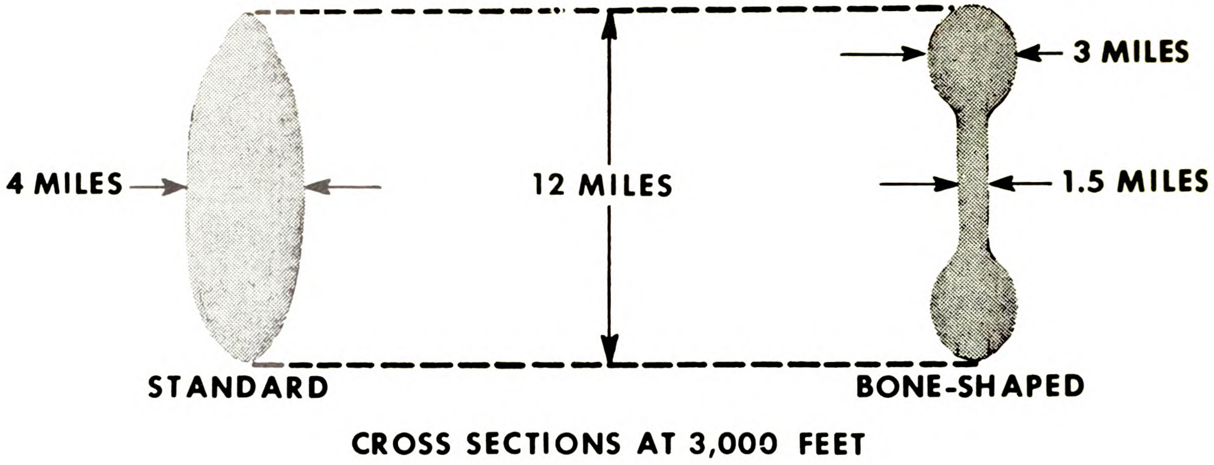


Figure 11-21.—Marker patterns.

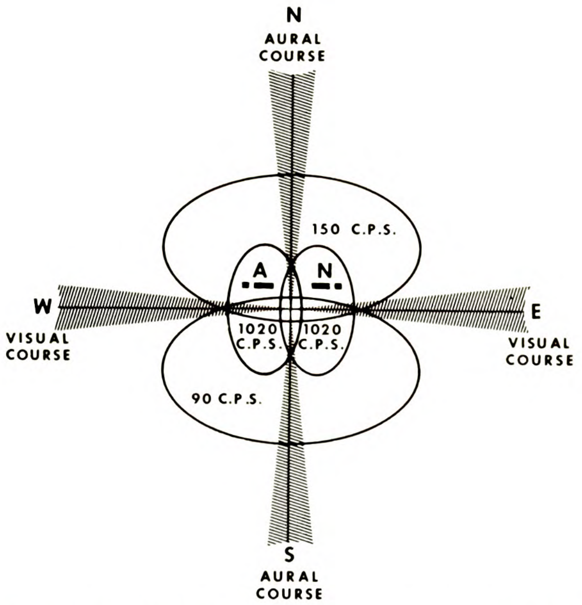


Figure 11-22.—Radiation patterns and courses of the VAR system.

and visual signals to form beat frequencies in the receiving equipment.

The visual courses are defined by the intersection of two oval patterns of radio energy, one containing 90-cycle and the other 150-cycle modulation. The pattern to the north of the visual course is generally called the blue area and that to the south, the yellow area. The visual course is flown by observing the deviation of the vertical pointer of a left-right meter on the instrument panel of the plane. When equal amounts of 90- and 150-cycle energy are received, the pointer is centered and the plane is on the visual course.

The aural signals are received as 1,020-cycle tones interrupted to form the code letters when off the aural course and as a steady tone when on course. When flying the visual course, the aural signals reverse when the plane flies over the range station.

Voice transmissions are made from the VAR facility by modulating the carrier wave radiated from the center antenna. The pilot selects the range signals or the voice transmissions by means of the same type of filter which is employed in reception of the low-frequency range signals. Six channels are used by this facility. These are situated between 108.3 and 110.3 megacycles.

INSTRUMENT LANDING SYSTEM

The instrument landing system (ILS), one of the facilities of the new federal airways, operates in the VHF portion of the spectrum. The entire system consists of a runway localizer, a glide path signal, and marker beacons for position location.

The localizer equipment produces a radio course alined with the center of an airport runway. As in the visual course of the VAR radio range, the on-course signal results from equal reception of two signals, one containing 90-cycle modulation and the other containing 150-cycle modulation. On one side of the runway center line the radio receiver develops an output in which 150-cycle tone predominates. This is called the blue sector. On the other side of the center line, 90-cycle output is greater and this area is called the yellow sector.

In the aircraft receiver, the output circuit contains a balanced rectifier connected to a zero-center microammeter which remains centered as long as equal amounts of the two tones are present. Deviation of the aircraft to either side of the final approach course results in deviation of the indicator as shown in figure 11-23.

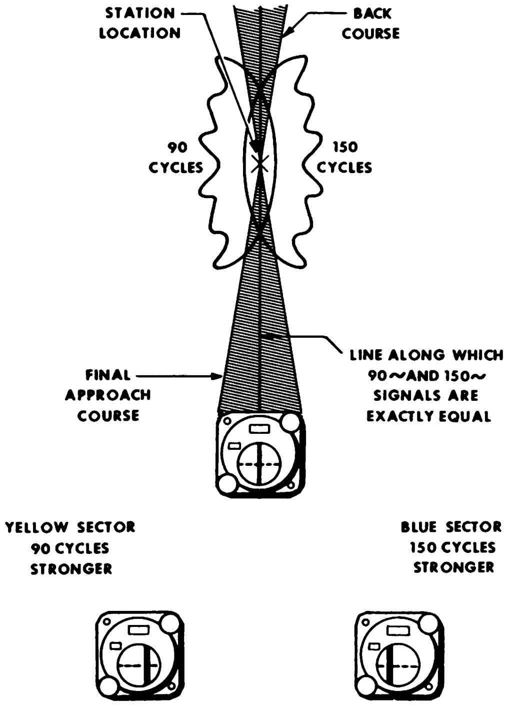

STATION LOCATION
BACK COURSE
90 CYCLES
150 CYCLES
LINE ALONG WHICH 90~AND 150~ SIGNALS ARE EXACTLY EQUAL
FINAL APPROACH COURSE
YELLOW SECTOR 90 CYCLES STRONGER
BLUE SECTOR 150 CYCLES STRONGER

Figure 11-23.—Tone localizer pattern and instrument indications.

The localizer transmitter operates at about 110 megacycles. The transmissions are made from an antenna array containing eight loops situated about 1,500 feet from the end of the runway. Three kinds of transmissions are made. Six of the loops radiate sideband energy only. Sidebands containing 90-cycle modulation and those containing 150-cycle modulation are separated by a sharp null directed along the center line of the runway. Two of the loops radiate the carrier wave containing equal amounts of 90- and 150-cycle tones and this signal is sent along the null separating the sectors. Signals are received in any location, but as indicated in the figure, only along the runway center line are the 90- and 150-cycle tones received in exactly equal amounts.

The glide path is a radio beam which gives vertical guidance to the pilot assisting him in making the correct angle of descent to the runway. Glide path signals are radiated from two antennas which are driven by a crystal-controlled transmitter operating at about 330 megacycles. The power output is about 25 watts.

One antenna radiates a beam which is very broad in the vertical plane. This beam contains signals modulated by a 90-cycle tone. The other antenna emits signals modulated at 150 cycles in many lobes which are very narrow in the vertical plane. The undesired lobes are too high (fig. 11-24) to be encountered in a normal approach. The glide path is an area of intersection between the broad 90-cycle lobe and the lowest of the 150-cycle lobes. In this area, which is a conical beam, the receiver develops equal amounts of 90-cycle and 150-cycle signals in the output. The beam is inclined about 2.5 degrees with the horizontal. (See fig. 11-24.)

The glide path receiver is a crystal-controlled superheterodyne which is powered entirely from a 28-volt, d-c source and requires no high-voltage power. The receiver audio output containing the 90- and 150-cycle tones is filtered and the two signals are rectified separately. The resulting direct current is applied to a zero-center microammeter which indicates by means of a horizontal pointer. (The localizer and glide path indicators are actually mounted on the same instrument. However, in many military installations the glide path equipment is not employed.) The pilot flies the glide path by keeping the horizontal pointer in the center of the dial.

Figure 11-24 shows how the glide path would appear to the receiver and indicators in an aircraft. The cross section is shown from the runway to a distance of 10 miles. At that range the glide path appears to be 920 feet thick (vertically), and 4,600 feet wide. By keeping both pointers centered, the pilot may fly to the runway without seeing the ground. However, once over the runway the pilot must be able to see the runway in order to land.

Marker beacons and compass locators are used in connection with the instrument landing system. The markers are signals which indicate the position of the plane along the approach to the runway and are similar to the Z-marker equipment employed in low-frequency range stations. Two markers are used in each installation. The location of each is identified both by tone modulation and by a signal lamp. The outer marker is located about 4.5 miles from the end of the runway. The signal is modulated by a 400-cycle tone and is keyed in long dashes (two dashes per second). The inner marker,

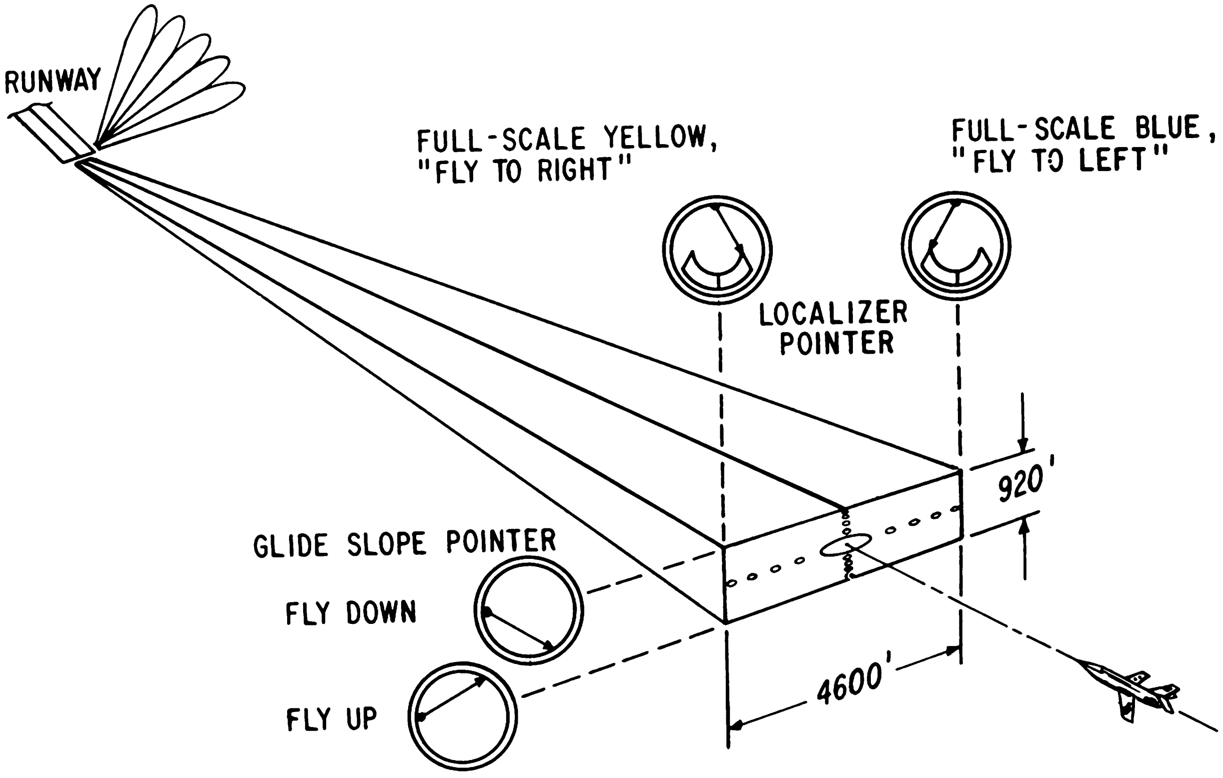


Figure 11-24.—Cross section of ILS course.

located at a distance of 3,500 feet, is modulated at 1,300 cycles per second (a higher pitched tone) and is keyed with alternate dots and dashes.

Compass locators are low-power nondirectional beacons which provide signals for automatic direction finding equipment. They operate between 200 to 400 kilocycles and are located near the marker beacon transmitters. The locator near the outer marker is coded with the first two letters of the localizer transmitter identification letters and the locator near the inner marker employs the last two letters of the call signal.

THE OMNIDIRECTIONAL RANGE

As the name VOR (VHF, omnidirectional range) implies, the omnidirectional, or all-directional range station provides the pilot with courses from any point in its service area. It produces an unlimited number of radials, any one of which is a radio path to the station. Operation is in the VHF portion of the radio spectrum with the result that interference from atmospheric and precipitation static is negligible. The navigational information is presented in a visual form, is constantly available, and is provided regardless of the position of the aircraft in the service area.

The basic provision of the VOR facility is a means of determining the angular position, or azimuth, of an aircraft with respect to the station. This measurement is made in the airborne receiver which determines the phase difference of two 30-cycle tones derived from two signals radiated from the range station transmitting antenna array. One signal, called the REFERENCE PHASE, is broadcast in a nondirectional radiation pattern. At all points on a circle having the station as a center, corresponding parts of this 30-cycle modulation occur at exactly the same time. Since the phase of this signal is independent of azimuth, it is used as a reference for comparison with another 30-cycle variation derived from a signal called the VARIABLE PHASE.

The variable phase signal is radiated in a figure-of-eight pattern which revolves about the transmitting antenna in a way somewhat similar to a rotating searchlight beam. The pattern consists of a positive and a negative lobe which turn together at 1,800 r.p.m., or 30 revolutions per second. As a result of the rotation of the pattern, the signal induced in the receiver is amplitude modulated with 30-cycle variations. The receiver develops this tone and compares it with the reference signal. The amount of phase difference between the two depends on the location of the plane with respect to the station. A phase measuring circuit in the receiver enables the pilot to determine the magnetic bearing and also to select and fly a range course to the station on any desired bearing.

As shown in figure 11-25, the VOR transmitter is modulated both by a 9.96-kc. subcarrier and by an additional component either of voice or the station identification code characters. The subcarrier is frequency modulated at 30-c.p.s. and is generated by a notched tone wheel rotating in a magnetic field. The purpose of the subcarrier is to provide a means for separating the 30-cycle tone of the reference phase from the variable tone of the same frequency.

The modulated output of the transmitter is applied both to a modulation eliminator and to the center loop antenna of a five-element array. There it is radiated to form the reference phase signal. The modulation eliminator is a clipper which removes the amplitude modulaion from the carrier. The unmodulated output s fed to a capacity goniometer which serves as a mechanical sideband generator. The gonimeter is a motor-driven, double capacitor in which one set of stator plates is displaced 90 egrees from the other set. The rotor plates o which the RF signal is applied are driven at ,800 r.p.m., or 30 revolutions per second. Two outputs are derived, one from each set of tator plates. These two signals contain modlation components (30 c.p.s.) which differ in phase by 90 degrees because of the capacitor late relationship. One output is fed to one pair of diagonally opposite loop antennas and he other is fed to the remaining pair of loops n the square array. Each pair of corner antennas produces a figure-eight radiation pattern. These two patterns are displayed from each her by 90 degrees both in space and in time hase. The resultant pattern is the sum of the wo crossed figure-eight patterns and consists the rotating field described above.

Figure 11-25 shows in simplified form the ssential elements of the receiver which enable e pilot to select and fly a range course to the mnidirectional station. In the VOR transmitng system, the reference and the variable signals are in phase along the zero-degree radial (bearing due south of the station). The phase difference between the signals changes proportionately with the change in bearing to the station. The airborne receiver measures the magnetic bearing of the range station by the following general method:

1. The reference and variable signals are received and separated.
2. The two signals are then applied to a phase bridge containing a zero-center meter (the vertical pointer instrument used with the ILS localizer beam).
3. The reference signal is applied through a phase shifter, or course selector, equipped with a dial calibrated in degrees from 0 to 360.
4. The reference signal is shifted (in phase) by adjustment of the calibrated course selector until the phase bridge is brought to a zero indication. The amount of phase shift required to zero the bridge is proportional to the magnetic bearing of the range station.

To fly a given course to the station, the pilot sets the phase shifter until the calibrated dial reads the desired bearing. With this setting the reference signal is phased so that a balanced condition of the course indicator needle is shown as long as the plane is on the selected radial. To follow the radial to the station, the pilot flies so as to keep the vertical needle of the course indicator in the center position.

As indicated in figure 11-25, the receiver is an ordinary superheterodyne through the second detector. Following the second detector, filter circuits separate the 9,960-c.p.s. subcarrier and the variable phase 30-cycle signals. The FM subcarrier is then applied to an FM detector which recovers the 30-cycle reference voltage. After passing through the phase shifter (course selector), the reference voltage is combined with the variable signal in the phase meter circuit.

The phase meter is a bridge which is balanced (indicated by a center position of the course indicator) when the two 30-cycle variations applied to it differ in phase by 90 degrees. At this relation, the vector sum of the voltages in the upper half of the circuit is equal to the vector sum of those in the lower half. The two sums are converted into d.c. by rectifiers and applied to the zero-center instrument with opposite polarity.

The phase shifter contains two transformer windings mounted at right angles, and these two are fed with two components of the reference signal. A third winding rotates inside the other

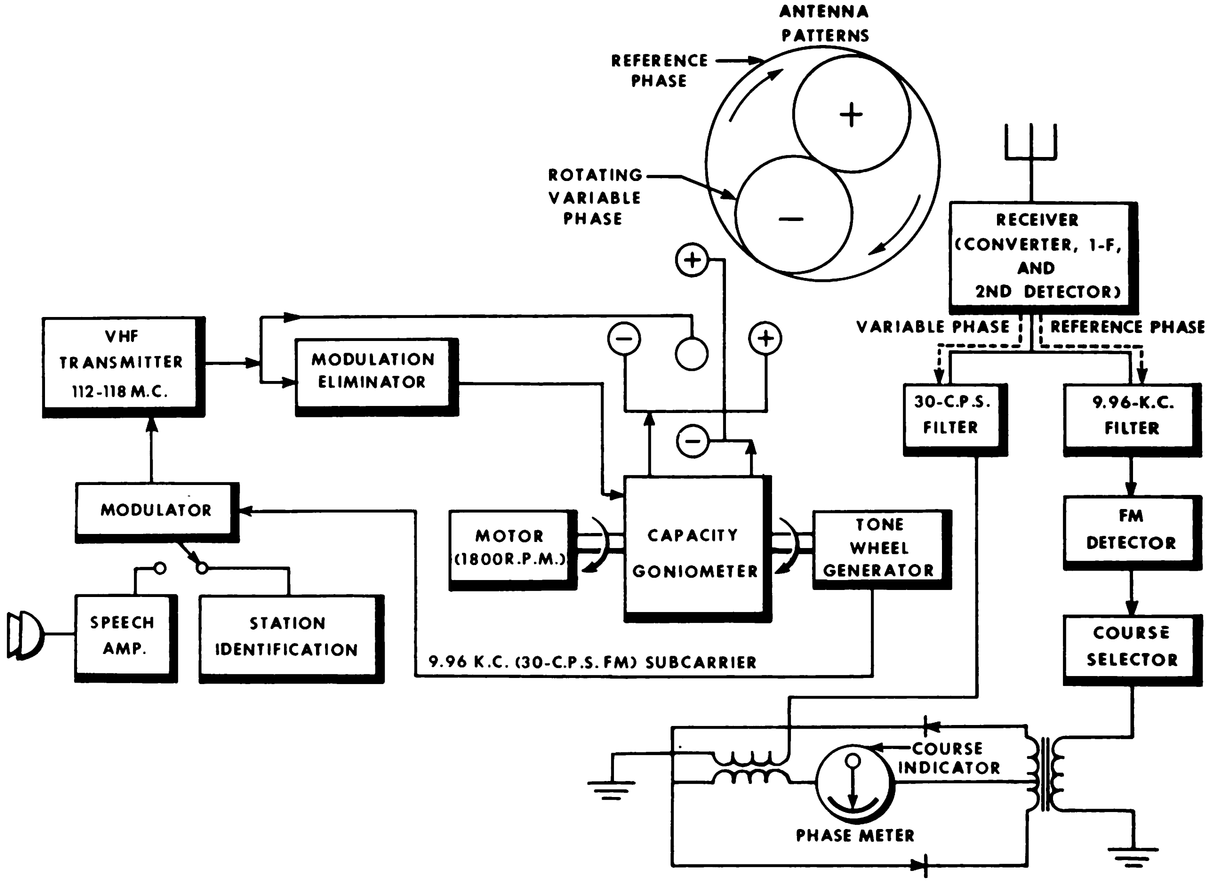


Figure 11-25.—Omnirange system fundamentals.

two coils, and a voltage is induced in it with a phase angle which depends on the rotor position with respect to the two primaries. The rotor coil is attached to a counter-type dial which is calibrated in degrees to indicate the magnetic bearing to the range station. A manually adjustable set knob is used to position the rotor for the desired magnetic course.

The vertical pointer of the course indicator also shows a centered position when the aircraft is flying on the reciprocal radial which is 180 degrees from the selected course. (This results from the fact that these are two positions of the phase shifter which will balance the bridge circuit.) A TO-FROM INDICATOR is included in the course selector instrument which enables the pilot to know when he is flying the reciprocal of the radial shown on the course dial. This indicator reads TO when the aircraft is on the selected radial and FROM when it is on the reciprocal of this radial. For example, in flying a 90-degree radial to the station, the course indicator needle remains centered and the TO-FROM indicator reads TO while the plane is approaching the station from the west. After passing over the station while maintaining the same heading, the course needle remains centered but the TO-FROM indicator then reads FROM.

DISTANCE MEASURING EQUIPMENT

Eventually each omnirange station will be equipped with distance measuring equipment (DME). By means of this facility, airborne units will provide the pilot with constant visual indications of his distance from the range station. The combined omni and DME information provide all the primary data required for point-to-point air navigation. These data consist of exact knowledge of the plane's distance from and direction to one or more points.

DME units operate similarly to IFF and radar beacons. The airborne unit, called the

INTERROGATOR, transmits a train of short pulses which are received by the ground unit, called a TRANSPONDOR. After reception of the challenging pulses, the ground station using suitable circuits shapes them into trigger impulses which modulate a pulse transmitter to send a reply to the aircraft. Upon reception by the interrogator, the elapsed time between the challenge and the reply is measured. This interval is a measure of the distance separating the aircraft and the transpondor beacon.

The challenge sent by the aircraft consists of spaced pulses in the 960-990 megacycle band. The ground station equipment is set to accept only those signals which have the correct spacing and which are on the correct frequency. The frequency and spacing characteristics define a challenge channel. The reply consists of a train of RF pulses in the 1,185-1,215 megacycle band. The combination of the challenge and reply channels is called an OPERATING CHANNEL.

Up to 50 aircraft can use the same ground beacon to obtain DME information without interference.

The airborne unit, shown in block diagram form in figure 11-26, consists essentially of timing circuits, search and tracking circuits, and the indicator meter.

The TIMING CIRCUITS measure the time interval between the transmission of a challenging pulse from the transmitter and the reception of the corresponding reply pulses. As in radar operation, this time value is a measure of the distance separating the plane and the beacon.

The SEARCH CIRCUITS operate by causing the equipment to seek out a reply after each challenge. Briefly, the search function is as follows: the receiver is triggered on by gating circuits and operates for a very brief period of time after each challenge. The gate pulse which activates the receiver is separated from the challenge by an interval of time delay, *T* Interval *T* is made to vary between 0 and 1,200 microseconds, corresponding to a range of distances from zero to approximately 112 miles. The receiver goes into operation after each challenge, but delayed by a different interval of time after each emitted signal. The

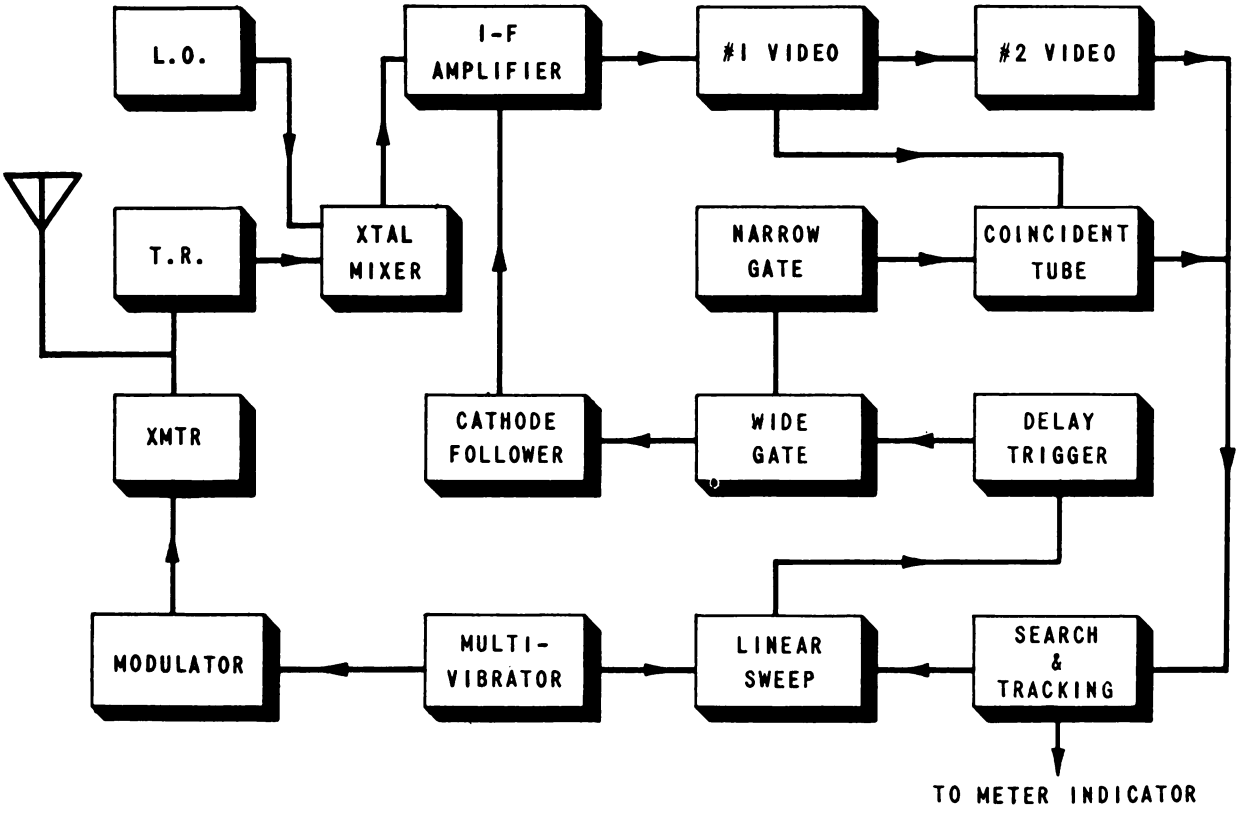


Figure 11-26.—Block diagram of airborne DME unit.

receiver, then, can accept beacon replies only when the delay time, *T*, is equal to the time required for a challenge signal to reach the beacon and the reply to return. When the time delay is such that the beacon reply is received, the search circuits are disconnected and the tracking operation begins in which the receiver holds the signal which it has found. When this occurs, the distance of the beacon is indicated on the dial of the indicator. This is accomplished by measuring the delay time *T*. The value of *T* is controlled by a voltage to which it is directly proportional. When the search circuits have discovered a reply, the control voltage is applied to a voltmeter which is calibrated in miles.

The TRACKING CIRCUITS of the equipment adjust the time of operation of the receiver so that the received beacon reply is accepted even though the distance between the plane and ground station is constantly changing. In tracking operation the receiver is controlled by the action of two gating impulses. These are the wide gate (20 microseconds) and the narrow gate (10 microseconds). A signal received in the wide gate increases the delay time and one during the narrow gate decreases it. Thus the two control gates effectively bracket the reply signal and keep the receiver operating at the time when the reply pulses arrive. As a result, the distance meter continually indicates the number of miles between the plane and the beacon.

The automatic search circuits can be started again when the pilot wishes to track on another beacon. If the new beacon is more distant than the first, a release switch is pressed which causes the delay to increase and the search circuits begin operating to seek out the delay time corresponding to the station. If the alternative beacon is nearer than the first, a zero switch is pressed which causes the delay time to start again from zero before resuming search operation.

A pilot lamp near the DME meter indicates the presence or absence of a signal, and is burning if no signals are present. The beacon transmissions are gap-coded; that is, the replies are arranged so that intervening spaces form the Morse code letters assigned to identify the beacon. When the signals are being received, the pilot lamp flashes on and off, giving the beacon code identifier. When the plane is at a distance beyond the operating range of the beacon, the light burns continuously to warn the pilot that the meter reading is no longer the true distance but is the distance at which the signal was last received.

The usefulness of the information provided by VOR stations equipped with distance measuring equipment can be greatly extended by means of a device called a COURSE LINE COMPUTER. The computer makes it possible to fly a constantly indicated course between any two points within the reception range of a VOR-DME station. The pilot does not need to proceed directly to or from the range station. He merely sets the desired course into the computer and the instrument uses the VOR-DME signals to guide him.

A part of the basic data required by the computer concerns the exact location of the desired destination with respect to the range station. The location is expressed by two values called R and theta as shown in (A) of figure 11-27.

The distance of any unknown point, P, is called R since it can be visualized as a radius of a circle having the ground station as a center. The magnetic bearing (theta) of the point from the station is an angle whose value determines the position of the point on the circumference of the circle.

The additional data required by the computer is indicated in (B) of figure 11-27. There a navigational problem is illustrated in which it is desired to fly from point X to point Y. The pilot sets up the course by dialing the R and theta values of the destination into the computer. He then dials the course angle (90 degrees in the example) or magnetic bearing of the destination from the starting point. The frequency dial of the equipment is set to the assigned frequency of the range station.

While the plane is en route over the selected course, the computer calculates instantly and continually the distance from the VOR station that will place the aircraft on the line XY. At the same time, it takes the measured distance from the station provided by the airborne DME unit and compares this value with the calculated distance. This gives an indication of any deviation from the course line, and this information is shown by the vertical needle of the deviation meter. As long as the needle is centered, the plane is flying the selected course.

The computer also calculates continuously the distance of the aircraft from the destination and indicates the result on an indicator dial as "destination distance." When the distance meter reads zero and the course deviation is centered, the pilot knows he is over the destination.

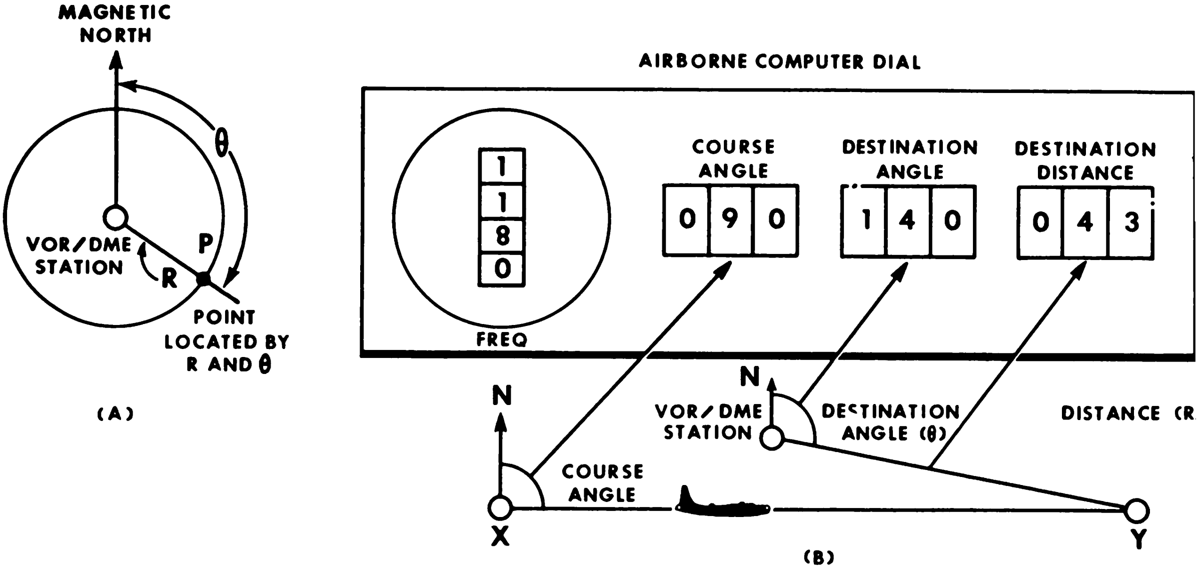


Figure 11-27.—Course line computer settings.

In some computers, the course information is not presented by means of dials but is given in pictorial form. In these, the image of a small airplane is projected onto the surface of a chart or map. The progress of the aircraft is represented by the movement of the image over the chart, and the pilot watches this simulated motion to determine his position and progress along the selected course.

AIRBORNE EQUIPMENT

AN/ARN-14 Radio Receivers

The AN/ARN-14 series consists of five radio receivers which are designed to provide the pilot or other members of the aircrew with all of the radio aids to navigation now available in the very high-frequency range. Three of the receivers of the series are used in Navy installations. These are the AN/ARN-14A (Bendix), the AN/ARN-14D (Bendix), and the AN/ARN-14E (Collins). The reception range of these receivers includes both military and commercial communication channels, omnidirectional range channels, tone localizer service, and visual-aural range (VAR) service.

PURPOSE OF THE EQUIPMENT

Each of the AN/ARN-14 units is an airborne navigation receiver equipped with three indicators to supply navigational data. The receivers also contain provision for audio output. T equipment is designed for the followi functions:

1. Reception of VHF omnirange signals wi visual display of on-course information.
2. Indication of the magnetic bearing of t omnirange station from the aircraft.
3. Indication of the magnetic heading of t aircraft.
4. Indication of the angular difference b tween a selected course and the magnetic hea ing of the aircraft.
5. Reception of tone localizer signals wi a visual display of this information on t course indicator instrument.
6. Indication of reciprocal courses by mea of a To-From indicator.
7. Indication by means of flag alarm ind cators when the signal level is unsatisfacto for localizer or omnirange operation.
8. Reception of voice facilities on the com munication channels and a voice transmissi superimposed on the navigation signals in t localizer and the omnirange bands.

FREQUENCY RANGE

The frequency range covered by all A ARN-14 receivers extends from 108 to 135 megacycles. Two hundred and eighty crysta controlled channels assigned for navigation aids and voice communications are provide These channels are spaced 100 kilocycl apart. The AN/ARN-14A receiver is wired for the following types of operation in the frequency ranges shown:

Frequency in megacycles	Use
108-110.9	Tone localizer
111-111.9	Weather broadcasts
112-117.9	Omnirange operation
118-121.9	Tower communication (voice)
122-135.9	Communications (voice)

The AN/ARN-14D and AN/ARN-14E receivers cover substantially the same frequency ranges except that tone localizer signals are received on odd tenths of megacycles between 108.1 and 111.9 mc. These receivers are wired for reception of omnirange stations located at airways terminals (TVOR stations) on even tenths of megacycles between 108 and 111.8 mc.

The major units of an AN/ARN-14 installation consist of three indicators, a radio receiver, a control panel, a dynamotor, an antenna, and two mountings. One of the mountings is associated with the receiver and one with the dynamotor.

Course Indicators

Course Indicator ID-249A/ARN is intended primarily for use by the pilot. It consists of (1) a To-From indicator, (2) flag alarms, (3) a course marker, (4) a marker beacon indicator, (5) a horizontal pointer used for glide path operation—this is usually inactive in Navy installations, (6) a relative heading pointer, (7) a vertical pointer for range and localizer operation, and (8) a radial selector knob. The instrument is illustrated in (A) of figure 11-28.

The radial selector knob marked SET is rotated to select a desired radial which is indicated through the course marker window. The To-From indicator is used only with omnidirectional range service. It differentiates between the selected radial and the reciprocal radial, and indicates TO when the aircraft is on or near the selected radial and FROM when the aircraft is on or near the reciprocal. The relative heading pointer indicates the heading of the aircraft with respect to the radial which is shown on the course marker. It operates in conjunction with signals from the aircraft compass system. The vertical pointer is used with the range and localizer services. It maintains a center position when on course and deviates when off course. The vertical flag alarm indicates OFF when the received signal strength is too weak for use, and the flag disappears from view when the received signal strength is sufficient for use.

Course Indicator ID-250/ARN, shown in (B) of figure 11-28 is also called the Radio Magnetic Indicator or RMI. It is located either in the navigator's compartment or in the cockpit. The rotating compass card is controlled by the remote indicating magnetic compass. The card rotates so that the magnetic heading of the aircraft is indicated against the fiducial marker at the top of the instrument face. The 0 degree mark on the rotating card always represents magnetic north and the fiducial marker represents the heading of the aircraft. The figure read on the rotating compass card at the pointed end of the double-barred pointer is the magnetic bearing of the omnidirection station as measured from magnetic north, or the magnetic heading to fly to reach the station. The front pointer is used in installations where another source of direction-finding information is available so that two different stations may be located. Ordinarily, in a single receiver installation, the rotors and stators of the motors which drive the pointers are connected in parallel so that both needles rotate together and indicate the same bearing.

Radio Indicator Control ID-251/ARN, shown in (C) of figure 11-28 provides a continuous indication of the magnetic bearing of the omnidirectional range station to which the receiver is tuned. It consists of a fiducial marker and a rotating bearing card which follows the azimuth position of the aircraft with respect to the VOR station. When the aircraft is in the effective receiving range of the VOR station and the receiver is tuned to the station frequency, the fiducial marker points to the radial on which the aircraft is required to fly to reach the station. Primarily, the unit is used for electrically combining the magnetic heading information from a magnetic compass with the directional information from the radio receiver to provide bearing indications for the operation of Course Indicator ID-250/ARN. Hence, the unit does not need to be observed visually and is usually located at a remote point in the aircraft.

Receiver

All the ARN-14 receivers cover the frequency range from 108 through 135.9 mc., and provide 280 channels spaced 100 kilocycles apart. In the ARN-14A and ARN-14D units (Bendix), a triple conversion superheterodyne

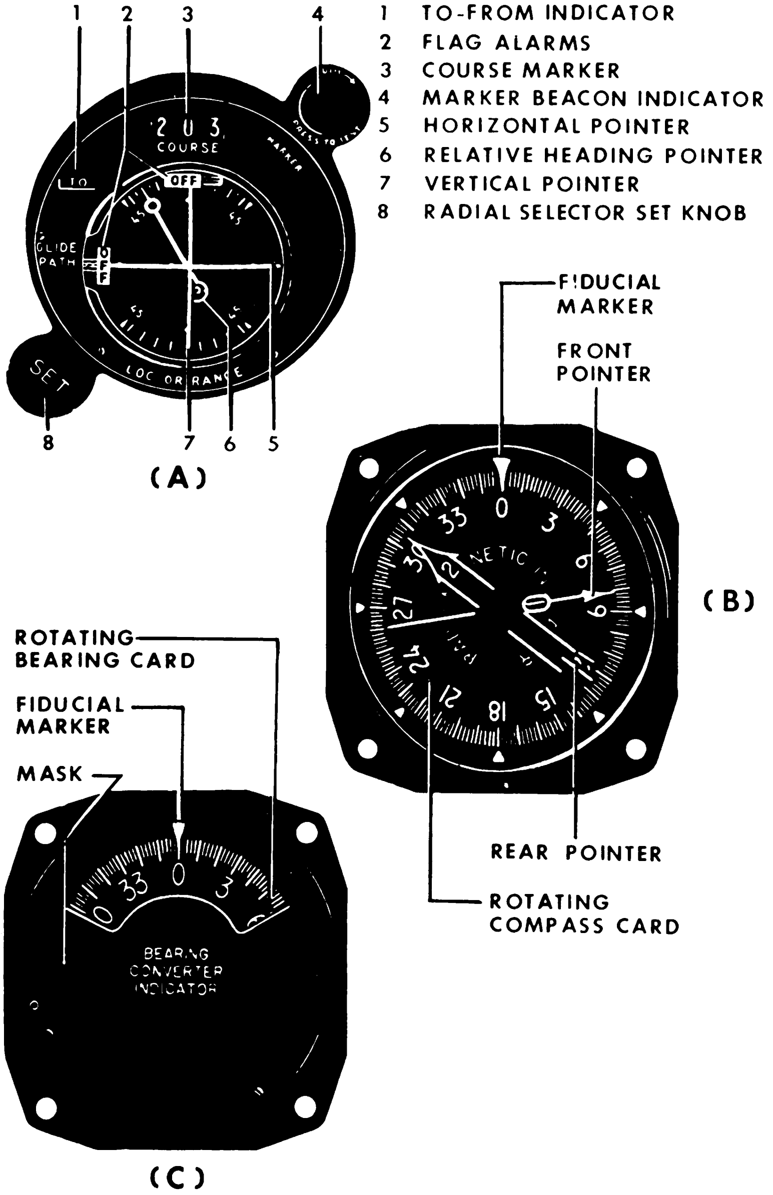


Figure 11-28.—AN/ARN-14 instruments. (A) Course indicator ID-249A/ARN; (B) course indicator ID-250/ARN; (C) radio indicator control ID-251/ARN.

system is employed using three crystal-controlled oscillators. Two of the local oscillators are controlled by 34 crystals and, in conjunction with the frequency selector circuits, provide crystal operation on each of the 280 channels in the receiver input. The other local oscillator is controlled by a separate crystal and generates a signal which is mixed with the second intermediate-frequency signal to produce a final IF voltage. The ARN-14E (Collins) receiver employs a double-conversion superheterodyne with crystal control to convert the received signals to a low-frequency value for demodulation.

The portion of the demodulated signals which contains voice modulation and station identification is fed to the audio channel where it is passed through a squelch circuit, a noise limiter, an audio amplifier, and an audio output stage. The final audio output is then applied to the aircraft interphone system. A volume knob on the control panel is used to determine the audio level. The portion of the signal which contains the omnirange and other navigational information is fed to the part of the receiver called the instrumentation circuits.

Control Panel

Remote control of the ARN-14 equipment is provided by a control panel which includes an ON-OFF switch, a volume control knob, two frequency selector knobs (whole megacycle and tenth megacycle), and a frequency indicator. The frequency indicator is a window through which the digits of the selected frequency appear. Since all frequencies covered by the receiver have 1 as the first digit, this number is fixed underneath the indicator window. The whole megacycle knob changes the next two digits from 08 to 35. The tenth megacycle selector knob changes the last digit from 0 to 0.9 in steps of tenth-megacycles.

DESCRIPTION OF RECEIVER OPERATION

The receiver, which is the principal part of the ARN-14 equipment, is shown in block diagram form in figure 11-29. It can be considered as being divided into three major sections. These are the radiofrequency, the audiofrequency, and the instrumentation sections. All signals pass through the RF section and are demodulated in the second detector. Following this stage, voice and station identification signals are applied to the audio section and finally to the interphone system. The navigational information derived from the detector is conveyed to the instrumentation circuits.

Signals from the antenna are fed through coaxial cable to the receiver which, in the model shown, is a double conversion superheterodyne. After conversion to relatively low frequencies for amplification, all signals are demodulated in a diode detector. Four types of signals are recovered from the carriers. These are as follows:

1. Audio voice communications and station identifications.
2. A 30-cycle variable phase signal used in omnirange operation.
3. A 9,960-cycle subcarrier which is frequency modulated with 30-cycle variations comprising the reference phase signals for omnirange operation.

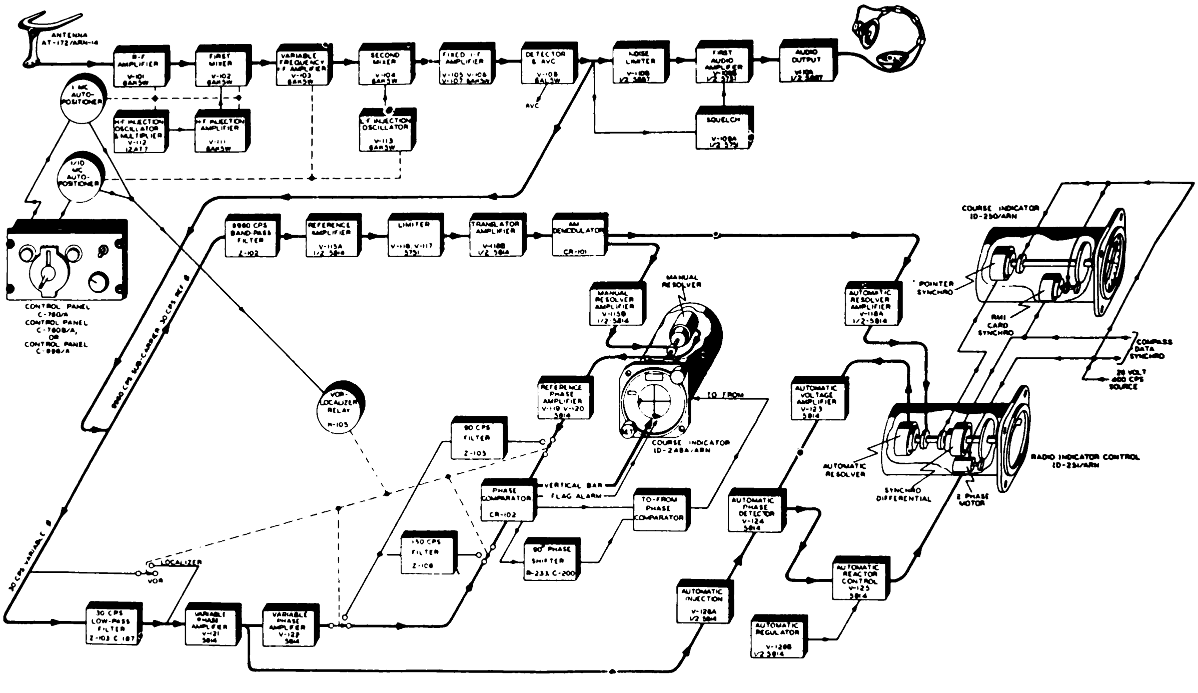

ANTENNA AT-172/ARN-14
R-F AMPLIFIER V-101 6AK5W
FIRST MIXER V-102 6AK5W
VARIABLE FREQUENCY I-F AMPLIFIER V-103 6AK5W
SECOND MIXER V-104 6AK5W
FIXED I-F AMPLIFIER V-105 V-106 V-107 6AK5W
DETECTOR & AVC V-108 6AL5W
AVC
NOISE LIMITER V-110B 1/2 5687
FIRST AUDIO AMPLIFIER V-109B 1/2 5751
AUDIO OUTPUT V-109 1/2 5687
SQUELCH V-109A 1/2 5751
1 MC AUTO-POSITIONER
1/10 MC AUTO-POSITIONER
H-F INJECTION OSCILLATOR & MULTIPLIER V-112 12AT7
H-F INJECTION AMPLIFIER V-111 6AK5W
L-F INJECTION OSCILLATOR V-113 6AK5W
CONTROL PANEL C-780/A
CONTROL PANEL C-780B/A, OR
CONTROL PANEL C-898/A
9960 CPS BAND-PASS FILTER Z-102
REFERENCE AMPLIFIER V-115A 1/2 5814
LIMITER V-116, V-117 5751
TRANSLATOR AMPLIFIER V-118B 1/2 5814
AM DEMODULATOR CR-101
9960 CPS SUB-CARRIER 30 CPS REF Ø
30 CPS VARIABLE Ø
VOR-LOCALIZER RELAY K-105
MANUAL RESOLVER
MANUAL RESOLVER AMPLIFIER V-115B 1/2-5814
REFERENCE PHASE AMPLIFIER V-119 V-120 5814
90 CPS FILTER Z-105
150 CPS FILTER Z-106
COURSE INDICATOR ID-248A/ARN
TO FROM
VERTICAL BAR
FLAG ALARM
PHASE COMPARATOR CR-102
TO-FROM PHASE COMPARATOR
90° PHASE SHIFTER R-233, C-200
LOCALIZER
VOR
30 CPS LOW-PASS FILTER Z-103 C 187
VARIABLE PHASE AMPLIFIER V-121 5814
VARIABLE PHASE AMPLIFIER V-122 5814
AUTOMATIC RESOLVER AMPLIFIER V-118A 1/2-5814
AUTOMATIC VOLTAGE AMPLIFIER V-123 5814
AUTOMATIC PHASE DETECTOR V-124 5814
AUTOMATIC INJECTION V-126A 1/2 5814
AUTOMATIC REACTOR CONTROL V-125 5814
AUTOMATIC REGULATOR V-126B 1/2 5814
COURSE INDICATOR ID-250/ARN
POINTER SYNCHRO
RMI CARD SYNCHRO
COMPASS DATA SYNCHRO
26 VOLT 400 CPS SOURCE
AUTOMATIC RESOLVER
SYNCHRO DIFFERENTIAL
2 PHASE MOTOR
RADIO INDICATOR CONTROL ID-251/ARN

Figure 11-29.—Block diagram of Receiver R-252A/ARN-14 (Collins).

4. A mixture of 90- and 150-cycle voltages received from tone localizer transmitters.

The last three of these types of signals are applied to the instrumentation section and the first type is applied to the audio circuits.

RF and Audio Sections

The receiver R-252/ARN-14 employs one stage of RF amplification. The grid and plate tank circuits of the RF amplifier, *V*101, pass a two-megacycle band and cover the frequency range of 108 to 135.9 megacycles in 14 steps. Following the RF stage is the first mixer, *V*102, into which is fed both the incoming signals and the injection signal from a three-stage exciter. The exciter consists of a crystal-controlled oscillator-multiplier, *V*112, and an amplifier, *V*111. When the signals are mixed with the injection voltage, an intermediate frequency is produced in the range of 19.45 to 21.35 megacycles. This component is amplified in a variable IF amplifier, *V*103, and then applied to the second mixer. The injection voltage for the second conversion is derived from a crystal oscillator-multiplier, *V*113. The second mixing process produces IF signals at a fixed frequency of 3.15 megacycles. After passing through three IF amplifiers, the signal is detected in *V*108.

The AVC system maintains the output of the receiver substantially constant over a wide range of incoming signal frequencies. A series noise limiter of the peak clipping type is employed to prevent sharp noise peaks and random voltage pulses from reaching the grid of the first audio amplifier tube. A squelch circuit biases the first audio grid to cutoff when no signal is being received and relaxes the audio grid voltage to allow the tube to operate only when a carrier signal is present in the receiver input.

Instrumentation Section

This section is divided into three parts. These are the REFERENCE PHASE, the VARIABLE PHASE, and the AUTOMATIC CIRCUITS. The reference phase circuit processes the 9,960-cycle subcarrier which is frequency modulated with the 30-cycle reference voltage. The variable phase circuit is concerned with the 30-cycle signal obtained from the detector. The automatic circuit accepts both the reference and the variable voltages.

The reference phase circuit receives the FM subcarrier from the second detector through a capacitor which blocks the 30-cycle variable phase signal but allows the higher-frequency subcarrier to pass. The latter voltage is amplified in *V*115A which contains a resonant band-pass filter circuit in the input. After amplification, the reference signal passes through two limiter stages each consisting of a twin triode connected as a combination of a cathode follower and a grounded grid amplifier. These convert the subcarrier into a series of square waves which are then applied to the translator amplifier. This circuit contains a parallel-resonant tuning circuit with a resonant frequency slightly higher than 9,960 c.p.s. so that the input signal falls on the slope of the resonance curve. The output of the amplifier contains an amplitude-modulated wave which is then detected in a bridge rectifier circuit which develops the 30-cycle reference voltage. This signal is applied to a manual resolver in the pilot's indicator. The resolver is a phase shifter used by the pilot to set the desired omni course. After being shifted in phase and amplified, the reference voltage is then applied to the phase comparator, *C*102, which is a phase bridge in which the reference and variable signals are compared in phase.

The variable phase circuit accepts the 30-cycle signal from the detector through a filter, amplifies it in two stages of amplification and finally applies it to the phase comparator. There it is compared with the reference voltage in a double bridge rectifier circuit. The cross pointer needle of Course Indicator ID-249A is positioned by the combined output voltages of the comparator bridge; and this indicator remains centered when the two signals differ in phase by 90 degrees.

The automatic circuit accepts a portion of the reference signal obtained from the translator, *C*101, and applies the signal to an automatic resolver or phase shifter. The variable signal is also applied to the automatic circuit in phase detector *V*124. The automatic resolver, operating with information from this circuit, shifts the phase of the reference signal so that it is always 90 degrees removed from the variable signal. The magnitude of the phase shift necessary to maintain this relationship is used as a means of operating Radio Indicator Control ID-251. This instrument in turn operates the double-barred pointer of Course Indicator ID-250 to reveal the magnetic bearing of the omnirange station to which the receiver is tuned.

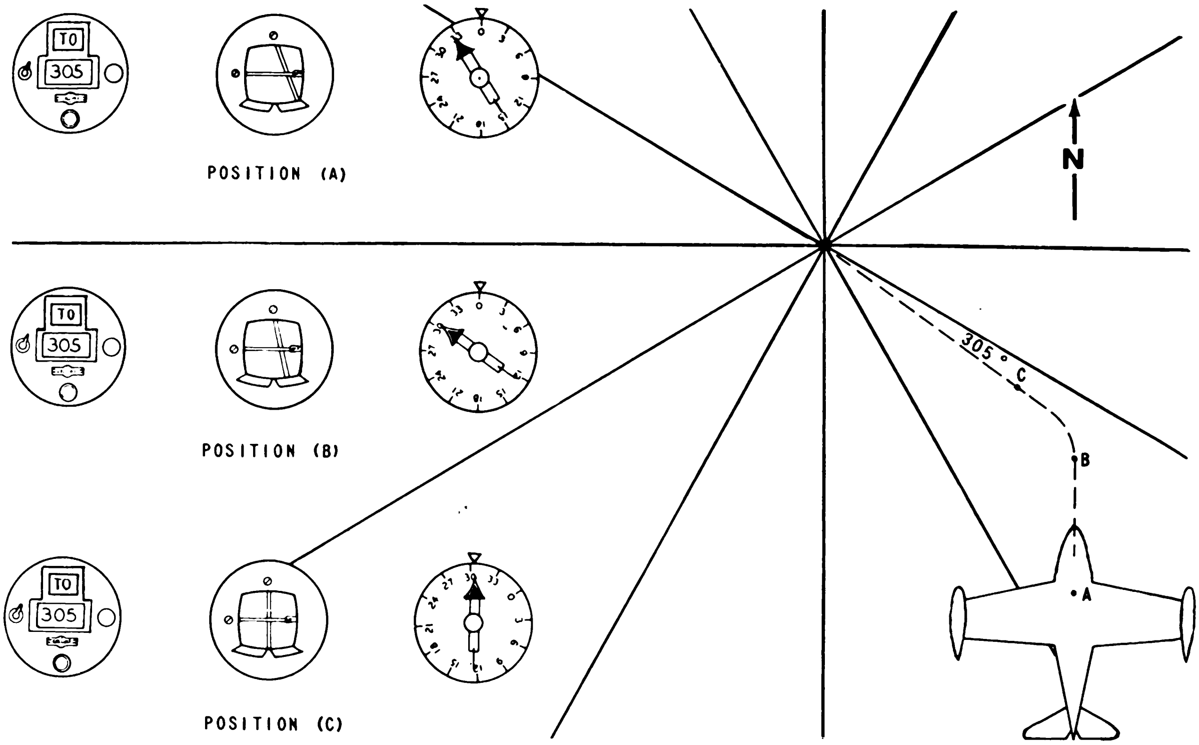


Figure 11-30.—Omnidirectional approach with typical instrument indications.

Interpretation of Omnidirectional Receiver Instruments

The use of the omnidirectional range in making an approach to the station together with the typical indications given by the instruments used in omnidirectional receivers is shown in figure 11-30.

Starting at position A, the needle of the Radio Magnetic Indicator points to the omnistation at the left, the bearing to the station being approximately 320 degrees. The magnetic scale of the RMI reads zero, since the airplane is flying directly north. The pilot, wishing to approach the range station along a course of 305, has set the course selector to read 305. The vertical needle of the course indicator reads to the right.

The airplane proceeds north to point B; and the needle of the RMI now reads 308 degrees. The azimuth card of the RMI still reads zero since the airplane is still headed due north. The vertical needle of the course indicator has swung in close to the center, showing that the airplane is near the desired track. At this point the pilot starts to turn to the left and arrives at point C. There the RMI reads 305 but points straight ahead indicating that the station is directly ahead of the aircraft. The magnetic scale of the RMI reads 305 also. The vertical needle of the course indicator is now centered, showing that the airplane is accurately established on course.

Figure 11-31 shows a plane as having passed over the omnirange station, the pilot's intention being to proceed to an intersection with a landing system localizer beam at the terminal field.

At point D the pilot's instruments show that he has just passed the range station but that he has slipped a little to the right of his desired track. The RMI needle has reversed and now points back toward the station, which now bears 160 degrees from the plane. The magnetic heading scale of the RMI shows 307 degrees, indicating that the heading is slightly in error to the right. The vertical course indicator needle points to the left of the aircraft. The To-From indicator now shows FROM. The track, or course, selected is now 305.

After readjusting to the correct course, the pilot arrives at point E. Here the pilot adjusts the frequency selector of the receiver to pick up the localizer signal of the ILS transmitter at the airport. (A typical value of this frequency is 109.0 megacycles.) At this time the instruments read as follows: The needle of the RMI is now inactive as the receiver has been tuned

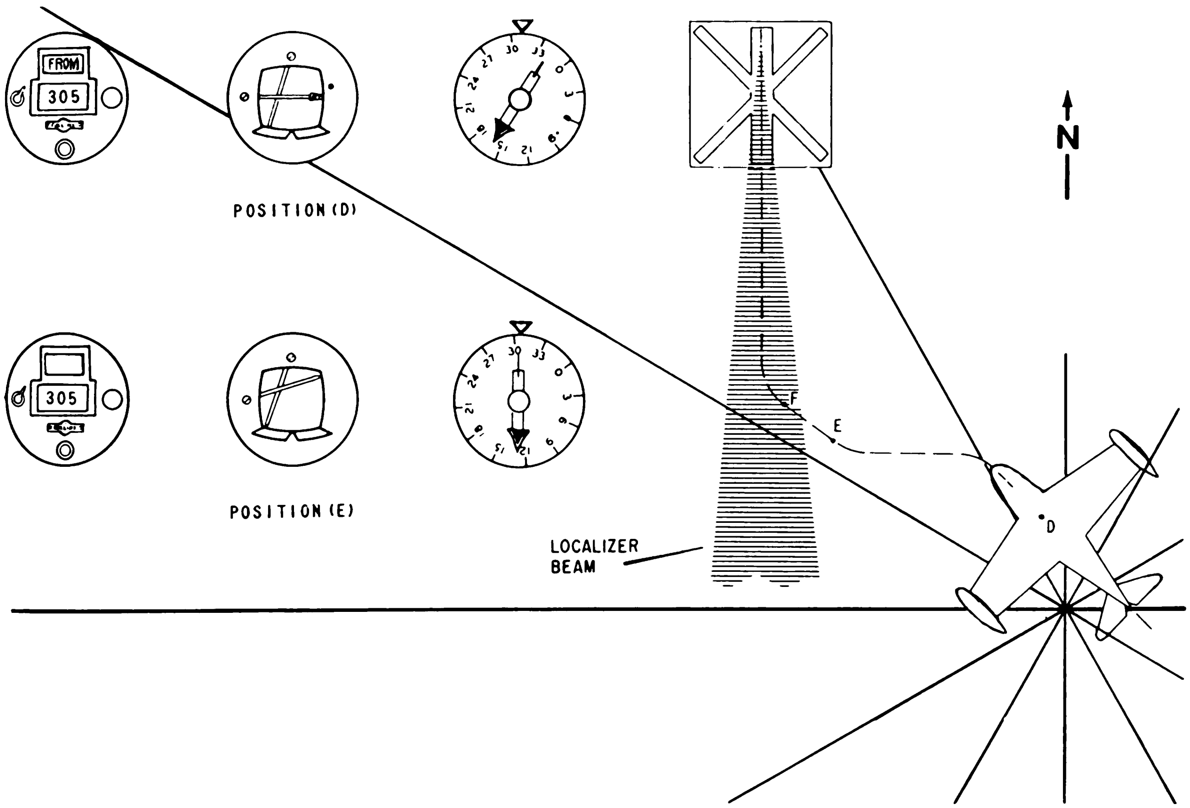


Figure 11-31.—Airport approach with typical instrument indications.

away from the VOR station frequency. The magnetic scale of the RMI is still in operation and shows the heading of the aircraft to be 305 degrees. The course indicator needle now indicates the position of the localizer beam and is deflected to the left showing that the desired runway line lies in that direction from the aircraft's position.

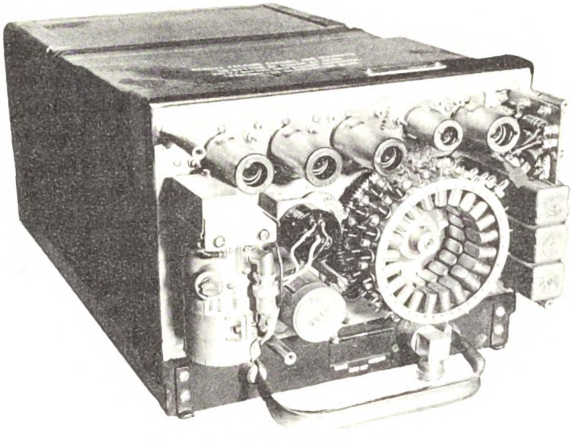
The pilot proceeds to point F where the instrument indications are approximately the same as shown at E, except that the course indicator needle has moved in toward center to show that the plane is approaching the desired course line. From this point the pilot is guided by the localizer signal and proceeds with his landing without further reference to the VOR system.

Radio Set AN/ARN-21

The fundamental theory of DME (distance measuring equipment) has been discussed. The ARN-21 is the type of DME installed in many naval aircraft, and it is discussed only briefly. The appropriate HSI should be consulted for detailed information relating to operation, theory, and adjustment of a particular set.

Radio Set AN/ARN-21 (fig. 11-32) is an airborne navigation interrogator-responsor designed to operate in conjunction with a surface navigation beacon transpondor such as Radio Set AN/URN-3. These two equipments comprise a radio navigation system which enables an equipped aircraft to obtain continuous indications of its distance and bearing from any selected beacon station located within a line-of-sight distance from the aircraft up to 195 nautical miles.

Both the airborne interrogator, AN/ARN-21, and the surface transpondor, AN/URN-3, have a receiver and a pulsed transmitter. The ARN-21 transmitter, part of Radio Receiver-Transmitter RT-220/ARN-21, initiates the interrogation process by radiating pulse signals. These signals, known as distance interrogation pulses, are detected by the URN-3 receiver and cause the URN-3 transmitter to respond with pulses known as the distance reply pulses. The distance reply pulses are detected by the receiver portion of the RT-220, where



FRONT COVER REMOVED

Figure 11-32.—Radio Set AN/ARN-21.

special range circuits measure the elapsed time between transmission of the interrogation pulses and the reception of the reply pulses. Other range circuits then convert the time difference into nautical miles which are displayed on the Range Indicator ID-310/ARN. (See fig. 11-32.)

In addition to the reply pulses, the URN-3 continuously transmits a series of coded and modulated radio frequency pulses to provide a reference bearing signal and a variable bearing signal. (These signals are used in the manner previously described in connection with high-frequency ADF.) These pulses are detected by the RT-220 where special azimuth circuits measure the phase difference between the reference bearing signal and the variable bearing signal. Other azimuth circuits then convert this phase difference into degrees which are displayed on the Azimuth Indicator ID-307/ARN.

At regular intervals the URN-3 also transmits a series of pulse signals which are keyed with identifying International Morse Code characters. When these signals are received by the RT-220 they are detected by a circuit which reproduces the code as a keyed audio tone.

Satisfactory operation of the ARN-21 is dependent upon the satisfactory operation of the URN-3. Therefore, both the air-to-surface transmission and the surface-to-air transmission must be effective for the realization of the capabilities of the system. The system has 126 frequency channels and will provide full service for over 100 aircraft on each channel. The large number of channels makes the arrangement of surface beacons flexible without producing signal interference thereby allowing for both extensive and intensive coverage in any area.

The coverage of a surfacd beacon, however, is limited to line-of-sight due to the frequency of operation. Bearing information, limited by the power output of the surface beacon, and the sensitivity of the RT-220, extends to over 200 nautical miles. Distance information, limited by range circuits and the Range Indicator ID-310, extends from 0 to 195 nautical miles. Although the power output of the RT-220 is reduced above the altitude of 35,000 feet, it is sufficient to cause flashover and limit the operation of the ARN-21 to an altitude of 50,000 feet.

The major units of the set are as follows: (Refer to fig. 11-32.)

RADIO RECEIVER-TRANSMITTER

The RT-220/ARN-21 transmits distance interrogation signals. It receives, in return, distance reply signals, variable bearing signals and reference bearing signals, and prepares the received information for display on the azimuth and range indicators. The transmitter section transmits pulse modulated signals in the frequency range of 1,025 to 1,150 mc. The receiver section operates in the frequency range of 962 to 1,024 mc. and 1,151 to 1,213 mc. There are 126 frequency channels, any one of which may be selected by setting the proper controls on Radio Set Control C-866.

AZIMUTH INDICATOR

The ID-307 has a dial face calibrated from zero to 360 degrees. It has a single centrally pivoted pointer, electronically controlled by the RT-220/ARN-21 azimuth circuits, which indicates the heading an aircraft must follow to reach the beacon to which the AN/ARN-21 is tuned. While the indicator is "searching" for the correct bearing, the pointer rotates at a rate which prevents bearing readings.

RANGE INDICATOR

The ID-310 has a single window which indicates distance in nautical miles between the aircraft and the surface beacon. The numerals in this window are electronically controlled by the receiver-transmitter range circuits, and serve to display the results computed electronically by these circuits. The maximum range of the ID-310 is 195 nautical miles. While the

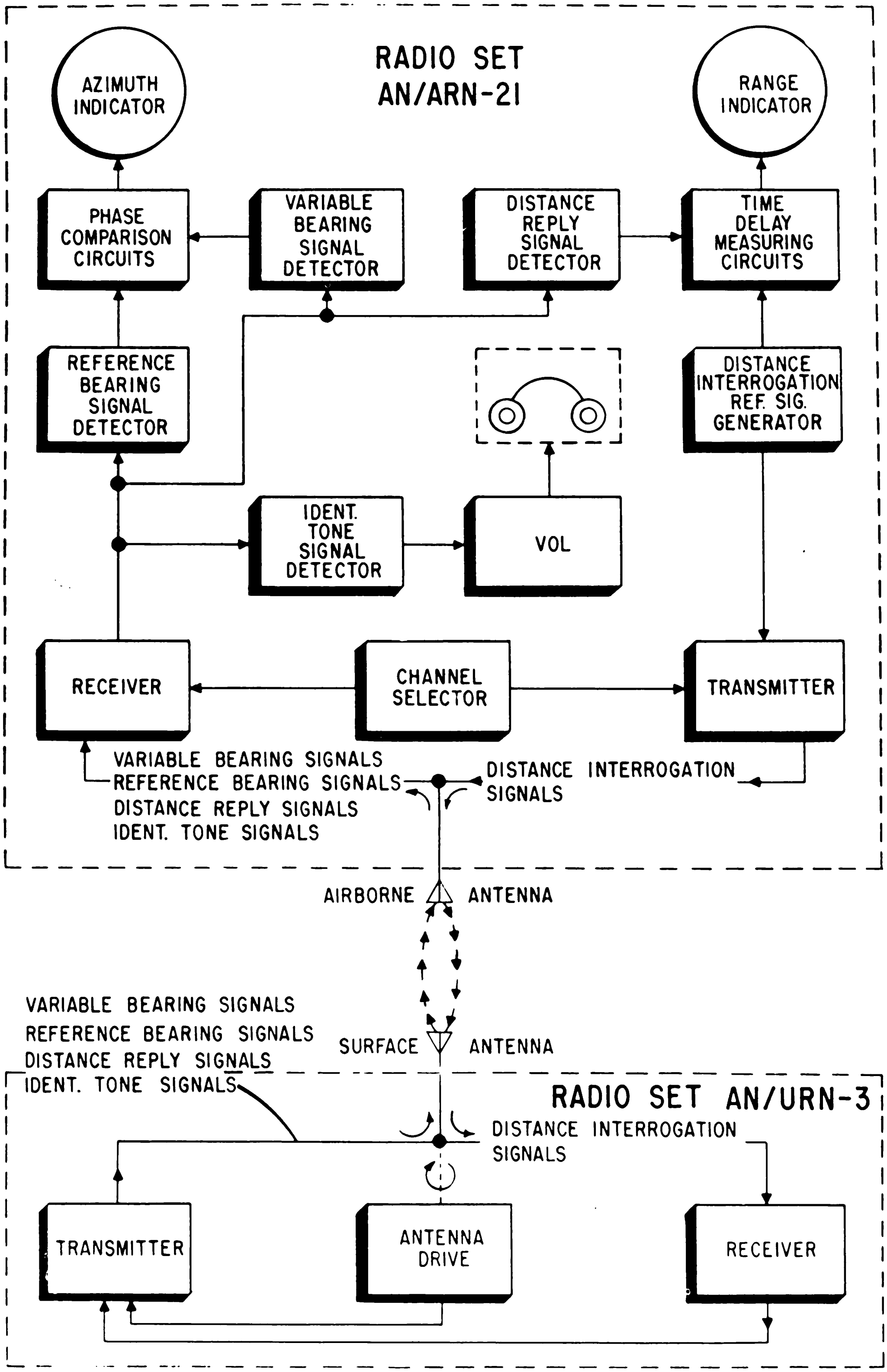

RADIO SET
AN/ARN-21
AZIMUTH INDICATOR
RANGE INDICATOR
PHASE COMPARISON CIRCUITS
VARIABLE BEARING SIGNAL DETECTOR
DISTANCE REPLY SIGNAL DETECTOR
TIME DELAY MEASURING CIRCUITS
REFERENCE BEARING SIGNAL DETECTOR
DISTANCE INTERROGATION REF. SIG. GENERATOR
IDENT. TONE SIGNAL DETECTOR
VOL
RECEIVER
CHANNEL SELECTOR
TRANSMITTER
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENT. TONE SIGNALS
DISTANCE INTERROGATION SIGNALS
AIRBORNE ANTENNA
SURFACE ANTENNA
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENT. TONE SIGNALS
RADIO SET AN/URN-3
DISTANCE INTERROGATION SIGNALS
TRANSMITTER
ANTENNA DRIVE
RECEIVER

Figure 11-33.—Overall system, simplified block diagram.

indicator is "searching" for the correct range, the rapidly rotating numbers are partially covered by a red flag which warns the operator against reading incorrect distance indications.

RADIO SET CONTROL

The radio set control, marked NAV, (fig. 11-32), contains the channel selector knobs, marked CHAN, pilot's identity tone level control, marked VOL, and the OFF, REC, T/R switch for energizing the equipment.

Channel selection is accomplished by turning the two knobs, marked CHAN on the control. The setting of the right-hand knob determines the unit figure of the channel number, while the left-hand knob determines the tens and hundreds figure of the channel number. The toggle switch to the left of the channel selector knob has three positions. The bottom position, marked OFF, turns the equipment off. The center position, marked REC, turns on the equipment so that only bearing information is displayed. The top position, marked T/R, operates the equipment so that both bearing and distance information is displayed. When the audio output from the equipment is connected to the pilot's headphones, the control marked VOL is used to regulate the level of the audio signal which is coded to identify the surface beacon to which the equipment has been tuned.

PHASE DETECTING NETWORK

This network, CV-279, is employed, in conjunction with Azimuth Indicator ID-307, to relay the ARN-21 bearing signals to the course indicator in such a manner that deviation of the aircraft course to the left or right of the URN-3 beacon will be indicated by the vertical crosspointer of the course indicator. Course Indicator ID-249 is accessory equipment, and is not shown as part of Radio Set AN/ARN-21, but appears in figure 11-28.

Figure 11-33 shows the overall operation of the ARN-21 system. The transceiver generates interrogation pulses and transmits them to the URN-3. Response from the URN-3, which gives distance and bearing information, is received by the ARN-21. By comparing the phase between the two signals emitted by the URN-3 an azimuth indication is obtained, and by measuring elapsed time between the interrogator pulse and the received pulse a range or distance indication is obtained.

Infrared Principles

Infrared (IR) is the term applied to a band of frequencies. The infrared band (IR band) lies just below the visible frequencies in the overall spectrum.

Examine figure 11-34. As you should already know, the audible frequencies cover a certain band in the spectrum, and when the next higher band of frequencies is considered, it is referred to as the radiofrequency band. Radiofrequencies are designated LF, MF, HF, VHF, UHF, SHF, AND EHF. Each designation merely refers to a band of frequencies in the spectrum. As frequency continues to increase, there is a transition from radiofrequencies to infrared, from infrared to visible, from visible to ultraviolet, and on into the cosmic rays. Each name merely designates a band of frequencies in the overall spectrum.

The infrared region lies just below the visible region. The lowest IR frequencies have the longest wavelengths and are termed "far infrared." Conversely, the highest IR frequencies have the shortest wavelengths and are termed "near infrared."

All objects radiate IR energy and can be detected because of it. Infrared radiation is not heat. However, heat is generated in any object that is struck by IR radiation, because frequencies in the IR range cause increased agitation of the molecules in the object. Also, any object that possesses heat will radiate energy at frequencies in the IR band. As the temperature of the heated object increases, the intensity of radiation increases; or, the warmer the object the stronger the IR radiation.

All objects possess heat. Theoretically, if an object were reduced to a temperature of absolute zero—(-273° C.)—it would possess no heat. Since absolute zero temperature has never been attained, it can be said that all objects possess heat. Therefore, all objects will radiate IR energy in degrees of intensity and at frequencies determined by their temperatures.

These and other phenomena concerning IR are employed in naval electronics. The IR radiation of objects is a definite radiation, and intense enough, in some cases, to be detected at great distances. The now famous Sidewinder missile utilizes this principle in its guidance

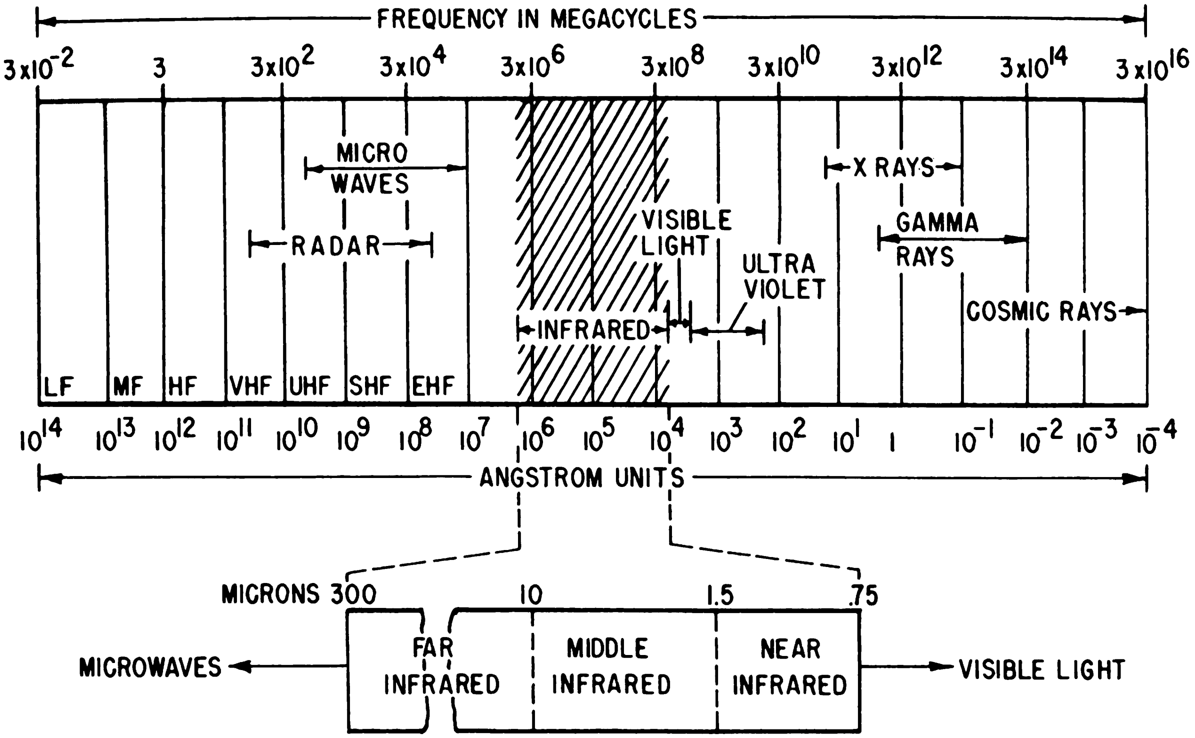


Figure 11-34.—Electromagnetic wave spectrum.

system. IR has long been used in photography for night photographs. It is also used for night vision, whereby an object in the dark can be located because of its IR radiation.

While it is unlikely that radar will ever be entirely replaced by IR, it is already an established fact that IR possesses certain advantages over radar. It is expected that radar and IR will work together as a team in many applications, such as fire control, guidance, and even search. There is no known method by which an IR detector can be jammed.

IR operation possesses certain inherent disadvantages. Detectors used to detect IR radiation must compromise between sensitivity and frequency response. IR radiation from an object will be greater at one frequency than at any other, and the radiation curve rises and falls sharply as temperature increases. The ideal detector would receive all IR frequencies equally well, and would produce a large signal voltage at any IR frequency with a very small amount of available radiation. Such a detector does not exist, so engineers must design detectors for the particular job to be done.

TYPES OF DETECTORS

IR detectors are of two general types, thermal and photoconductor.

One thermal detector called a bolometer, contains a tiny black-coated flake of a thermistor material less than 10 microns thick. A micron, which is a measure of distance, equals 1/10,000 of a centimeter and is a convenient term for designating wavelength at IR frequencies and higher. IR energy striking the bolometer causes a radical change in its temperature, and thereby its resistance. A current that is made to flow through the bolometer will vary in proportion to the resistance change. A bolometer, then, converts IR energy into heat energy, and the heating changes the bolometer's resistance. (The detector in figure 11-36 could be a bolometer.)

The bolometer will respond equally to all IR frequencies. Unfortunately, its sensitivity (output volts per watt of IR energy) is considerably below that of the photoconductor cell. Its action of converting IR energy into heat energy is also slow in comparison to the photoconductor cell's reaction time.

The photoconductor cell employs a tiny semiconductor crystal that absorbs photon energy from IR radiation, producing a change in its resistance or conductivity. This action is similar to the well known camera light meter. In comparison, the photoconductor cell requires 100 times less IR energy than a bolometer to produce the same output signal. Again, unfortunately, the photoconductor cell responds to only a narrow band of IR frequencies.

NOISE

Noise exists in any circuit that carries current. Most outside noises can be eliminated or drastically reduced by shielding and proper physical design, but thermal noise is an ever-present problem. Power supplies employed with IR detectors must be extremely well regulated; and since the IR radiation received by the detector is very weak, noise of any appreciable amount will be sufficient to cause serious trouble. Transistors, for instance, are useless in IR amplifiers because of inherent noise characteristics.

ATMOSPHERIC ATTENUATION

Figure 11-35 illustrates atmospheric attenuation on IR energy. This illustration shows that at sea level IR attenuation is greater at some frequencies than at others. Attenuation is maximum at a wavelength of 6 microns, and attenuation is minimum at about 3.8 microns. Those wavelengths between 8 and 13 microns in length can be thought of as "window frequencies." They exist in an area where attenuation is small. This means that an object whose temperature causes maximum radiation to occur at a frequency whose wavelength is 6 microns would be hard to detect at a great distance because of the large degree of attenuation. But, if its maximum radiation occurs at 3.8 microns it could be detected at a much greater distance.

Attenuation of IR energy is caused by moisture and carbon dioxide in the air. As altitude increases above sea level, the band width of each infrared window increases; therefore for high altitude air-to-air detection (above 30,000 feet), there is practically no attenuation.

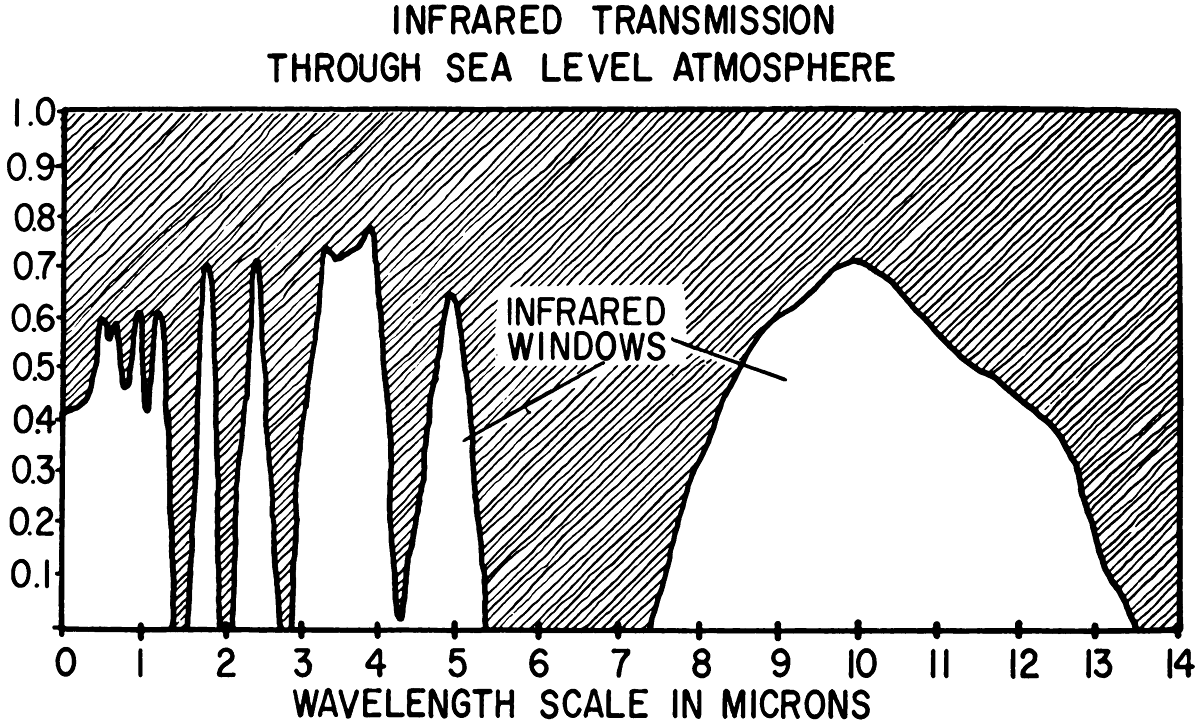


Figure 11-35.—Infrared windows.

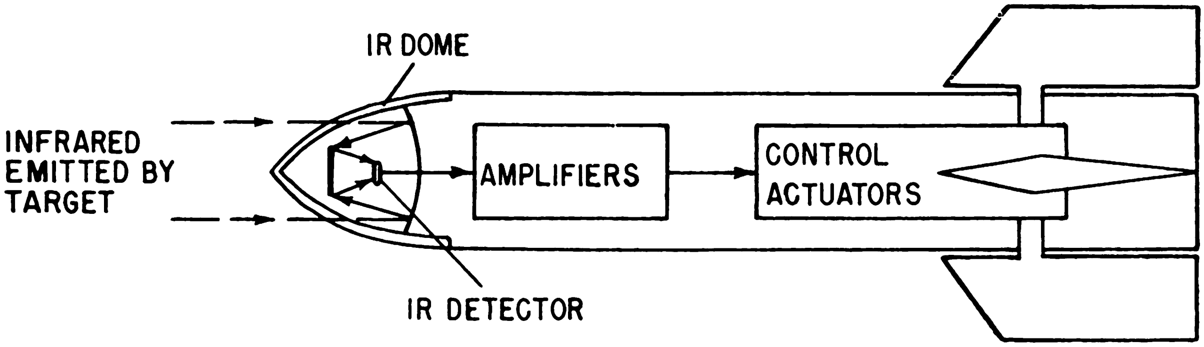


Figure 11-36.—IR detector and application.

ANTENNA (LENS)

An IR detector (antenna) is small as compared to airborne radar antennas. In some applications they may be no larger in diameter than a dime. The antenna utilizes a lens and mirror arrangement. These are used to concentrate the IR energy on the detector element. The lens are ground in the same manner as any optical lens and the mirror's parabolic characteristics are the same as those of radar antennas. Therefore, the IR antenna will automatically focus on a target by seeking the point of most intense radiation.

Figure 11-36 shows how an IR detector would be constructed to control a missile. IR rays pass through the IR dome (a dome of special construction) to the parabolic reflector, are reflected to the IR mirror in front, and concentrated on the detector. This assembly is arranged so that the "eye" (detector and two reflecting surfaces) always seeks the area of greatest IR concentration, thereby pointing at the target. Signal voltages from the detector are amplified and applied to the control surfaces to guide the missile to the target.

OTHER USES

Infrared employment is by no means limited to target detection. It is also used in short-range communication between sea level stations such as ships, and affords excellent security for that job. IR rays, like radio waves, travel in a straight line, and their use is limited to line-of-sight. Rapid attenuation at sea level works in favor of security for short-range communication between sea level stations.

Night photography is performed by IR, and it can produce a better visual presentation of terrain than the best mapping radars.

The navigation field has also been invaded by IR. Ground speed indicators are being developed that will compete with Doppler radar, and anticollision circuits are under experiment.

These are only a few of the possible applications of IR systems.

SCOPE OF PRESENTATION

This account is not intended to present all the possible applications of IR, or to delve very deeply into its theory. The material presented here is intended only as an introduction to a rapidly developing field. You are encouraged to seek further knowledge of IR as publications on the subject become available.

QUIZ

1. The useful loran range for day operation over sea water is about
   a. 700 miles
   b. 1,700 miles
   c. 400 miles
   d. 1,400 miles

2. In loran operation, what is the value of time difference used for?
   a. To locate a line of position on a chart
   b. To obtain a fix
   c. To compute distance from slave
   d. To add a correction factor

3. The omnidirectional range operates in what portion of the radio spectrum?
   a. LF
   b. HF
   c. VHF
   d. UHF

4. The loran receiver distinguishes between stations operating on the same channel by
   a. frequency
   b. pulse width
   c. pulse recurrence rate
   d. call signs

5. The basic units required in an ARDF system are
   a. directional antenna, receiver, and indicator system
   b. directional antenna, receiver, indicator system, and control section
   c. directional antenna, transmitter, indicator, and control section
   d. transmitter, receiver, directional antenna, and indicator system

6. The number of repetition rates utilized by the APN-70 is
   a. 144
   b. 24
   c. 96
   d. 48

7. The useful loran range for night operation over sea water is about
   a. 1,400 miles
   b. 400 miles
   c. 1,700 miles
   d. 700 miles

8. How many readings are necessary for a fix?
   a. One
   b. Two
   c. Three
   d. Four

9. The proper operation of omnirange equipment depends upon
   a. the phase comparison between two audio signals
   b. a directional antenna on the aircraft
   c. the coding of the transmitted signals
   d. the speed of the antenna's rotation

10. Loran operation differs from radar in that it does not utilize
    a. pulse-type transmission
    b. a radar receiver
    c. a visual presentation
    d. reflected signals principle

11. All ARDF systems may be used with reliability for
    a. plotting an aircraft fix
    b. homing and plotting a fix
    c. homing only
    d. as a prime navigation instrument

12. The variable delay system on low-frequency operation produces one output pulse during each
    a. L time
    b. L/2 time
    c. 1,625 microseconds
    d. 98,375 microseconds

13. In loran operation, the maximum time difference reading is found at the
    a. master station base line extension
    b. slave station base line extension
    c. midpoint between stations
    d. base line extensions of both master and slave

14. In loran operation, where is the base line extension located?
    a. Between A and B stations
    b. Behind either station A or B
    c. Behind station A only
    d. Behind station B only

15. The radiation pattern from the omnirange station is
    a. bidirectional
    b. unidirectional
    c. nondirectional
    d. quadridirectional

16. The RF receiver unit of the AN/APN-70 is designed to operate over the high-frequency loran band of
    a. 1,750 kc. to 1,950 kc.
    b. 90 kc. to 190 kc.
    c. 1,700 kc. to 2,000 kc.
    d. 100 kc. to 180 kc.

17. The AN/ARA-25 system requires the use of the
    a. AN/ARN-6
    b. AN/ARN-41
    c. AN/ARC-27
    d. AN/ARC-5

18. The repetition rate circuits provide outputs for all but which of the following circuits?
    a. Fixed delay circuits
    b. Automatic drift control circuits
    c. Sweep circuits
    d. Time sharing gain circuits

19. Loran was primarily designed for operation over
    a. long range over water
    b. short range over water
    c. long range over land
    d. short range over land

20. Where does the zero line exist when stations pulse simultaneously?
    a. Nearer to A than B
    b. Nearer to B than A
    c. Does not exist
    d. Equal distant from A and B

21. One advantage of the omnirange over the LF radio range is
    a. little or no interference from intervening objects or irregularity of terrain
    b. several stations in one area may operate on the same frequency
    c. increased number of frequencies available
    d. increased range

22. The direct reading in microseconds taken from the APN-70 is a measurement of
    a. time difference between arrival of master and slave pulses
    b. 42 time delay plus coding delay
    c. 42 time delay plus transit time
    d. transit time between master and slave station

23. The switching action of the ARA-25 directional antenna causes
    a. the antenna to have directional characteristics
    b. an increase in average power received
    c. modulation at the receiving element
    d. the signal voltage to vary at the null

24. The sweep and blanking circuits are triggered by the
    a. reset thyratron on function 1 and the pedestal ampere on functions 2, 3, 4, and 5
    b. pedestal amplifier on all functions
    c. reset thyratron on functions 3 and 5
    d. reset thyratron each L/2 time and give an L/2 sweep on all functions

25. What is the frequency of standard loran channels?
    a. 1.7-2 mc.
    b. 0.17-0.19 mc.
    c. 0.09-0.11 mc.
    d. 1.75-2.5 mc.

26. The slave station is delayed
    a. one-half pulse recurrence rate
    b. coding delay only
    c. one-half pulse recurrence rate plus coding delay
    d. one-half pulse recurrence rate minus coding delay

27. How many aircraft can obtain distance information from the same ground beacon without interference when using VHF omni?
    a. 50
    b. 100
    c. 195
    d. 200

28. During LF triad operation, the master transmitter is pulsed
    a. every L time
    b. every L/2 time
    c. at 1/2 the frequency of the slave transmitters
    d. every 40,000 microseconds

29. In loran operation, where is the time difference in arrival of pulses measured?
    a. Loran indicator
    b. Timer unit
    d. RF receiver unit
    d. Deflection unit

30. A number group on a line of position gives the operator what information?
    a. Channel number only
    b. Basic pulse recurrence rate only
    c. Specific pulse recurrence rate only
    d. All of the above

31. In the ARN-21, what is the maximum distance that range information may be obtained?
    a. 100 nautical miles
    b. 112 nautical miles
    c. 195 nautical miles
    d. 200 nautical miles

32. The 80 KC/XTAL oscillator is synchronized with the time base of the loran transmitter by the action of the
    a. counter circuits
    b. repetition rate circuits
    c. deflection circuits
    d. ADC circuits

33. In order to obtain the same information from the ARN-14 that is available from the ARN-21 you would
    a. increase the frequency to the UHF band
    b. install distance measuring equipment
    c. install a directional antenna on the aircraft
    d. pulse modulate the ground beacon station

34. In the ARN-21, the frequency spectrum is
    a. 1,025 mc. to 1,150 mc.
    b. 962 mc. to 1,150 mc.
    c. 962 mc. to 1,213 mc.
    d. 1,151 mc. to 1,213 mc.

CHAPTER 12

AIRBORNE RADAR

Radar increases the effectiveness of naval aircraft by adding new powers and capabilities to the human senses. It is unhampered by the ordinary obstacles to unaided vision such as darkness, fog, haze, and smoke. Radar reveals the presence and location of certain kinds of objects situated far beyond the range of normal vision, indicating their distance and bearing directly and with a high degree of accuracy. In short, the airborne radar set provides the pilot and operator with a pair of radio eyes that can pierce the surrounding darkness or overcast and "see" ships, land areas, cities, clouds, and other aircraft.

In some respects, radar detection is inferior to normal vision. Radar presentations reveal almost no detail and show only the general outlines of objects. The ability of radar to distinguish between various types of objects is limited, and it presents unwanted echoes from sea waves and land (called "clutter") as readily as from important targets. It is also subject to willful interference or jamming by the enemy. Radar is most successful in revealing isolated objects located in a background without numerous details. Good target subjects are ships at sea, aircraft in flight, and coastlines. In the map-like radar presentation of the PPI (plan position indicator) screen often employed in airborne search units, many details of complicated targets such as cities are clearly shown, but the presentation is considerably poorer in detail than an aerial photograph taken under conditions of good visibility.

While radar is a powerful aid to the aircraft, the aircraft in turn increases the powers of radar by supplying it with an elevated platform from which its effective range in detecting objects is greatly extended. The application of radar to airborne operations has been most successful in military aircraft and is now an indispensable part of the plane. In naval aircraft, the general purposes served by radar are the following:

1. Search and reconnaissance.
2. All-weather fighter or intercept operation.
3. Identification, friend or foe.
4. Navigation and beaconry.
5. Bombing, rocketry, and fire control.
6. Aircraft early warning or relay systems.
7. Antisubmarine warfare.
8. Aerial minelaying.

In its basic operation radar works on the echo principle. Radio waves are sent out from a powerful transmitter. A very small amount of the radiated energy is reflected from objects in the range of the set and returned to the radar receiver. After passing through the various stages of the receiver, the reflected signal is either converted into visual displays or some property of the signal is measured directly for some other type of display. The final presentation of the echo is used to reveal information concerning the object causing the reflection.

The waves emitted by the transmitter may be CW signals, frequency-modulated signals, or regularly recurring pulses of high power. One of these types, pulse radar, has been developed to a far greater extent than all others. Most of the equipment designed for the purposes mentioned above are pulse radar devices, although one very important unit, the absolute altimeter, is based on frequency-modulation operation in one of its versions.

In pulse radar sets, the transmitter radiates radio waves in brief bursts of extremely high power. The time duration of the emitted pulse is very short compared with the interval between pulses. During these intervals the transmitter is idle and the receiver accepts reflections soon after the pulse leaves the transmitter. Echoes from more distant objects return at a slightly later time. After a length of time sufficient to allow echoes to return from the most distant objects in the range covered, the transmitter is turned on for another pulse and the operation is repeated.

This general method of operation is employed in airborne radar sets used for search and reconnaissance. Only one antenna is necessary with the pulse system.

Airborne Search Radar

Search radar, the basic type used in nost all radar-equipped planes, shows the nge and azimuth of targets such as ships, ands, coastlines, and other aircraft within reach of its beam. It is frequently used to tect enemy ships; and by means of associated mbing equipment, is employed in making nd bombing runs on them. Search radar is effective aid to air navigation since it ex- its land masses and storm clouds on the dar screen and is equipped to display coded nals from ground-based radar beacon sta- ns. It works in conjunction with the IFF stem which identifies the ships and aircraft ected as friendly or hostile by means of led replies.

RANGE MEASUREMENT

The measurement of range, or distance, by dar methods is based on the fact that radiated energy travels through space at a constant ocity, the speed of light, which is about ,300 statute miles per second. Expressed in t rather than miles, this speed is 983,644,000 t per second (or about 984 feet per micro- ond).

Unless otherwise specified, Navy search dar sets are calibrated in nautical miles of ge. One nautical mile is equal to 6,076.10333 t. If this number of feet is divided by the nber of feet traveled by a radar pulse in microsecond (983.664), the quotient is 77, or approximately 6.18 microseconds nautical mile. Hence, the radar pulse ers one nautical mile in 6.18 microseconds.

The radar set determines range by measur- the elapsed time during which the emitted se travels to the target and returns. Since -way travel is involved, a total time of 12.36 roseconds must elapse between the start of pulse and its return, provided the target is a range of one nautical mile. The range in tical miles of any object can then be found neasuring the time elapsing during a round of the radar pulse (in microseconds) and iding this quantity by 12.36. In equation m, this is

$$\text{Range} = \frac{\text{Elapsed time}}{12.36}$$

In range measurements based on this relation, most systems employ a cathode-ray tube indicator. A time scale is provided by sweeping the electron beam across the screen by means of a linearly rising voltage resulting in a visible trace line on which equal distances correspond to equal time intervals. (The linear sweep is explained fully in chapter 7 under "Oscilloscope.") The echo signals from targets are then superimposed on the time scale in such a way that their distances from the transmitter are revealed. Figure 12-1 illustrates range measurement by means of a basic type of indicator, the A-scope.

The radar system is pulsed many times each second, and a time base, or sweep, is produced on the CRT with each pulse. The result is that the moving spot of light in the cathode-ray tube appears as a continuous bright line. The radar data are presented as vertical deflections (pips) of the moving beam.

Assume that the beam travels 5 inches from left to right across the screen in 123.6 microseconds. The 5-inch trace then represents 10 nautical miles of radar range, since 12.36 microseconds correspond to 1 nautical mile of two-way travel. (Each half inch of trace represents 1 nautical mile of range.)

The figure illustrates the action occurring during the radiation of a single pulse. In (A) a 1-microsecond pulse leaves the transmitter and is represented on the indicator by a large vertical deflection, whose position on the display marks the zero range point. In (B) the outgoing pulse strikes a target 5 miles distant from the transmitter, and a small amount of the energy is reflected. This occurs 30.9 microseconds after the start of the pulse; and in this time, the beam in the indicator tube has reached a point 1-1/4 inches to the right of the zero range pip on the screen. In (C) a small part of the echo from the target has returned to the antenna and enters the receiver 61.8 microseconds after the start of the pulse. The receiver applies an impulse resulting from the reflected signal, causing a small deflection at a point 2-1/2 inches to the right of the starting point of the trace. This pip indicates the presence of an object 5 miles away.

When 123.6 microseconds have elapsed, the greater portion of the outgoing pulse has reached a point in space 20 miles distant from the radar set. The beam in the indicator tube

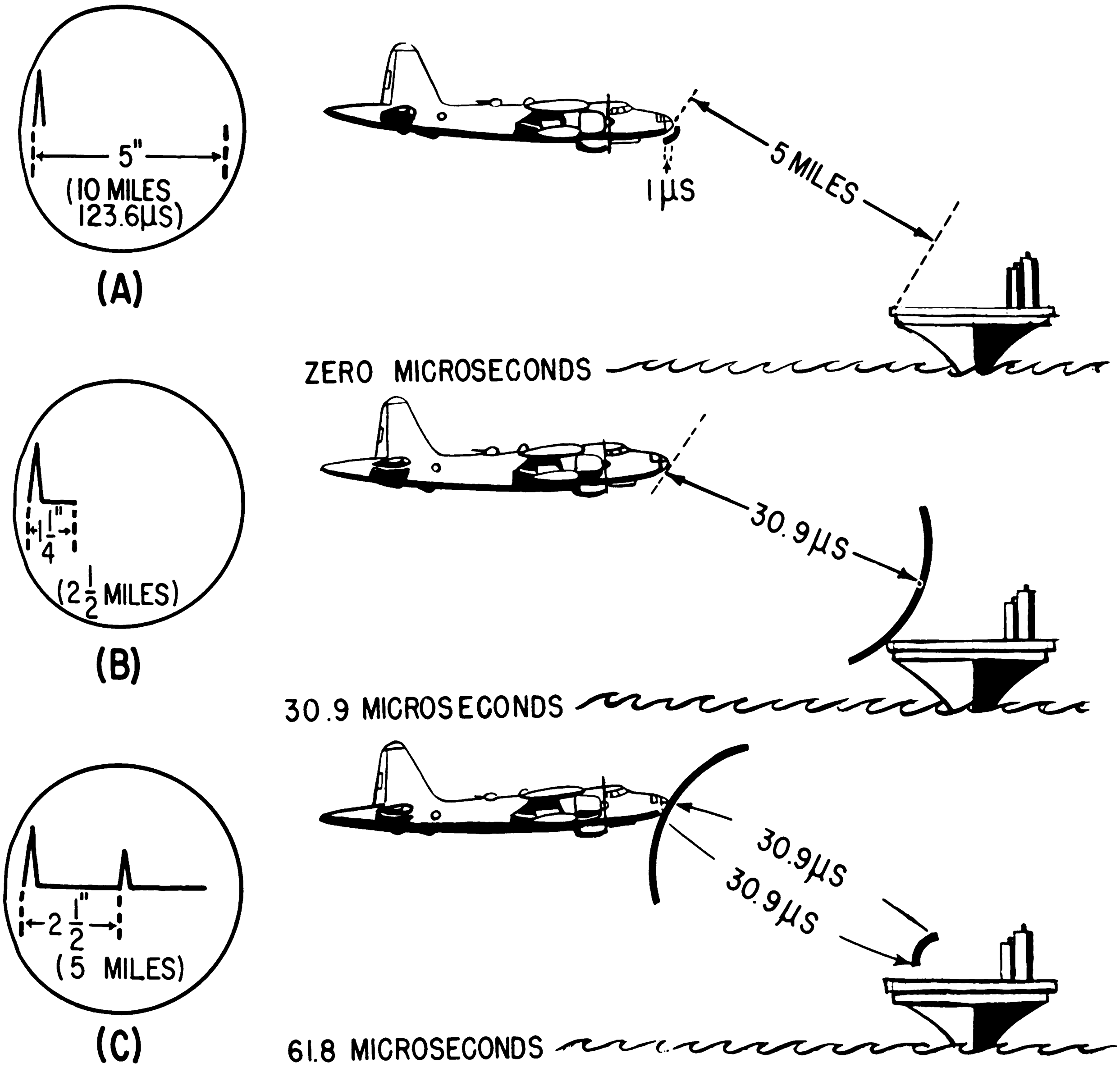


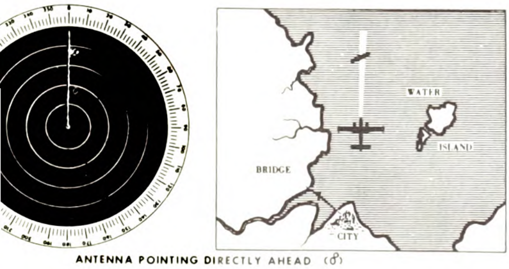
Figure 12-1.—Range measurement with cathode-ray tube.

has reached the right side of the screen 5 inches from the starting point. A blanking voltage is now applied to the grid of the cathode-ray tube and extinguishes the beam. Deflecting voltages are applied which will start the next sweep at the left side of the screen. The system is then ready to repeat the same action with another pulse.

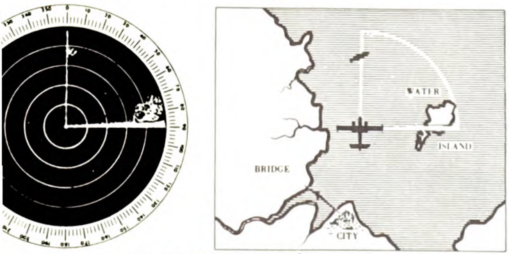
In most systems the target range is read directly from the radar screen by the use of range markers. These are lines or dots which divide the screen into regular intervals representing distance, appearing as vertical lines, dots, or as concentric circles depending on the type of scope presentation in use. The markers are produced electronically by means of an oscillator which generates voltage variations at regular time intervals. These impulses are applied to the indicator in addition to the sweep voltage and the target signals and cause the range lines to appear on the screen. The range scale is determined by the frequency of the marker generator. For example, if the impulses are applied every 12.36 microseconds, the resulting markers divide the screen into 1-mile intervals.

PPI PRESENTATION

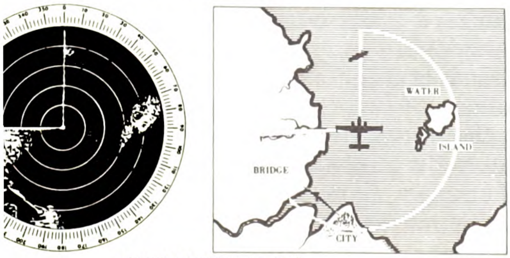
e basic airborne radar presentation is PI (plan position indicator) which pre- a circular, map-like picture of the area ed. The targets appear as bright spots sitions on the screen which represent range and bearing. A highly directional na sends out pulses in a narrow beam and ves echoes from the targets. Only the s that are within the beam return echoes t the antenna must be pointing at a given in order to detect it. The antenna is d either in a 360-degree circle around ane or else in a fanning motion covering icular sector, usually of about 60 degrees. e basic 360-degree scan used with the ndicator is illustrated in figure 12-2. time the transmitter sends out a pulse, ectron beam in the indicator tube sweeps the center of the tube outward to a point e edge which depends on the direction in the antenna is pointing. If an echo is re- d, a bright spot appears which is located at a distance from the screen center proportional to the range of the target.



ANTENNA POINTING DIRECTLY AHEAD (0°)



ANTENNA POINTING TO 90°



ANTENNA POINTING TO 270°

Figure 12-2.—PPI presentation.

Currents in the deflection coils of the CRT indicator rotate the trace around a fixed pivot point at the center of the screen in synchronism with the antenna, and the bearing of the target is indicated by the radial position of the time trace line.

In using the PPI scope to find the relative bearings of targets, the top of the screen corresponds to a dead-ahead position of the antenna. The outer edge of the screen is equivalent to the horizon. In some indicators, a graduated azimuth ring is fitted at the outer edge of the screen and a transparent mask inscribed with a line is fitted over the tube face. The relative bearing of a given target is read on the graduated azimuth ring. It is the value under the line on the movable mask when this line has been set so as to bisect the target image on the screen.

In many search radar sets, true bearing operation is also provided in which the top of the indicator display is oriented with true north by signals supplied by the flux valve compass of the airplane. The indicator remains in this position regardless of the heading of the plane and the PPI scope is read as a map.

In operational equipment, the PPI presentation is used in many forms. These include open center display, target discrimination display, sector scan, true bearing indication, and altitude delay operation. These displays are illustrated in the portion of this chapter which is concerned with the AN/APS-33 search set.

COMPONENTS OF THE SYSTEM

Search radar equipments vary considerably in detail depending on the amount of information and the accuracy of the data which they are required to supply. However, all systems of search radar using pulse modulation work on essentially the same principles, and their basic operations depend on the same kinds of major components. A basic search system is shown in simplified block diagram form in figure 12-3.

The SYNCHRONIZER is the timing unit and is the heart of the entire system. It produces trigger pulses which control and coordinate the circuits of the system so that each operates at the correct time. In most systems it governs the number of pulses the transmitter produces in each second (called the pulse

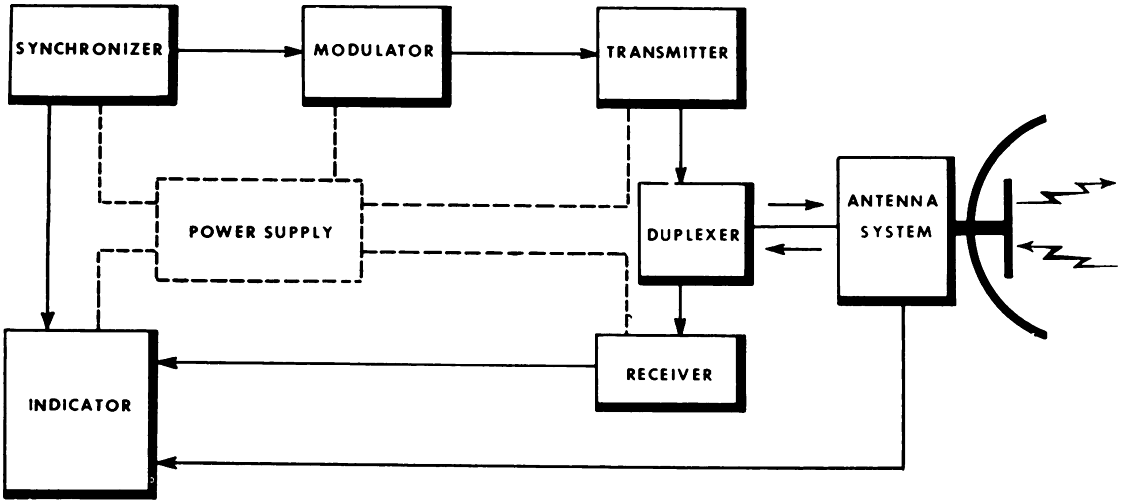


Figure 12-3.—Block diagram of basic airborne radar system.

repetition frequency or pulse recurrence rate). It coordinates the sweep voltage in the indicator tube with the firing of the transmitter, and contains provisions for delaying the beginning of the sweep to give special types of display (such as open center and target discrimination operation). The synchronizer contains the circuits which generate the range marker voltages and the trigger pulses which unblank the indicator tube when the trace starts to appear on the screen. Pulses supplied by the synchronizer are also used to indirectly control the associated equipment used with the search system.

The MODULATOR controls the operation of the transmitter by applying high-voltage pulses of rectangular shape. The pulses are usually supplied by charging a section of artificial transmission line in the modulator to a high potential during the interval between pulses. The modulator action begins when a trigger pulse from the synchronizer is applied to an electronic switch tube in the modulator unit. The switch tube terminates the artificial line and causes it to discharge a rectangular pulse through the transmitter tube. The length of time during which energy is transmitted is called the pulse width. In airborne applications, the modulator unit is usually enclosed in a container and operated under a constant pressure to prevent high-voltage arcing.

The TRANSMITTER consists principally of a magnetron which oscillates at extremely high frequency throughout the interval of the pulse applied by the modulator. The magnetron produces the electromagnetic energy which is radiated from the antenna into space. Airborne search radar sets employ microwaves, a typical value of wavelength being about 3 centimeters. The output of the magnetron is conducted to the antenna through waveguide transmission lines consisting of hollow metal tubing.

The ANTENNA SYSTEM has two general purposes. It radiates pulses of microwave energy developed by the magnetron, confining the waves into a narrow beam. In addition it receives the echo signals from targets and applies them to the receiver. The antenna system consists of waveguides, switching tubes, a reflector for beaming the radiated energy, a mechanism for rotating the reflector during operation, and servo units which coordinate the position of the indicator sweep with the position of the antenna reflector.

Since the same antenna is used both for transmitting and receiving, it is necessary to switch it alternately from one component to another. This action is accomplished by the DUPLEXER which consists principally of the TR (transmit-receive) tube and the ATR (anti-TR) tube. These are resonant cavities containing gas at a low pressure. Arc-discharges take place in the cavities when the transmitter pulse is applied to the waveguide containing them. The TR tube prevents the transmitted pulse from entering the receiver and damaging the sensitive crystal mixer. When the transmitter is idle, both tubes are de-ionized, and the ATR tube serves to prevent reflected echoes from entering the magnetron, allowing them to flow into the receiver.

The RECEIVER is an extremely sensitive superheterodyne containing circuits with bandwidths capable of passing pulses of the type emitted by the transmitter. It is important that the receiver generate as little local noise voltage as possible to avoid masking weak echo pulses.

The signals from the antenna are usually applied first to a crystal mixer where they are mixed with the output of the local oscillator, a reflex klystron tube. The IF output resulting from the mixing process is then amplified in a number of IF stages. In most aircraft radar receivers the intermediate-frequency value is between 15 and 60 megacycles. A video detector converts the IF energy into video pulses. After passing through one or more stages of video amplification, the signals are applied to the cathode-ray indicator.

Aircraft radar receivers employ automatic frequency control to keep the receiver intermediate frequency from drifting. A typical method is as follows: A portion of the transmitter output is applied to a separate mixer, called the AFC mixer, to which some of the output from the klystron local oscillator is also applied. The AFC mixer develops the difference frequency of the two and applies this signal to a discriminator circuit. The discriminator output voltage is zero when the correct intermediate frequency is produced. But if the receiver local oscillator attempts to drift off frequency, the discriminator produces a d-c voltage which is positive or negative depending on whether the local oscillator frequency is too high or too low. The d-c output of the discriminator is then applied to the repeller plate of the klystron local oscillator. This corrects the klystron frequency until it differs from the frequency of the outgoing pulse by the proper amount.

The INDICATOR accepts the radar data such as video pulses, the range marker voltages, and sawtooth timing waves and presents them in a visual display on the screen of a cathode-ray tube. The entire assembly contains the cathode-ray tube and various electronic circuits necessary for presenting the desired information on the screen. These circuits include video amplifiers, diode clamping tubes, and the controls for adjusting the brilliance of the visual pattern.

Two general types of presentation are used in aircraft radar indicators—deflection modulated and intensity modulated displays. In the deflection method, the video pulse causes a momentary deflection of the cathode-ray electron beam and produces a pip in the trace to indicate a target echo. In the intensity method, the video signal is applied to the element of the CRT which controls the intensity of the electron beam, and the resulting target image is a bright spot of light. The A-scope is an example of the deflection method and the PPI is a typical intensity presentation.

Sawtooth timing waves of voltage or current are applied to the deflection circuits of the CRT to produce the time trace or sweep in the pattern. The synchronizing pulse which triggers the modulator and transmitter also serves to coordinate the start of the sweep with the action of the transmitter to make range measurements possible. Target bearing in most displays is indicated by synchronizing the position of the sweep line on the screen with the position of the antenna.

In addition to video pulses, range marker pips, and sweep voltages, a square wave pulse is applied to the indicator tube which blanks the beam between sweeps so that retrace lines do not appear on the screen.

THE AN/APS-33 AIRCRAFT RADAR SET

The APS-33 exhibits many of the general principles and features discussed in *Basic Electronics*, NavPers 10087. This system is a typical example of a very important class of aircraft radar electronic equipment.

Airborne radar sets such as the APS-33 are subject to certain operating conditions and limitations which are not found in other types of installations. One of the principal requirements in such equipment is the necessity for minimum weight. Each component must be designed so that it contributes the lowest possible amount to the total weight of the complete unit.

It is also necessary that aircraft sets have low power consumption since the electrical generating capacity in aircraft is limited. Furthermore, the equipment must operate efficiently under conditions of varying frequency.

Complete airborne radar installations are usually composed of many small parts instead of one or two large ones. This type of construction simplifies maintenance procedures, makes installation easy, and allows ready removal of damaged components for repair. The physical layout of the components in the plane is such that the weight of the cables used to connect the various subassemblies is as low as possible.

Aircraft radar sets must be protected from the adverse effects of widely varying pressure and temperature. Very high voltage is employed in the equipment, and in the low atmospheric pressures encountered at high altitudes, the possibility of arc-over is increased. In the low temperatures of these altitudes, water vapor collected in the RF components at low altitudes is very likely to condense. These difficulties are usually avoided by sealing the modulator and the receiver-transmitter units in pressure-tight containers and maintaining them under constant pressure at all altitudes.

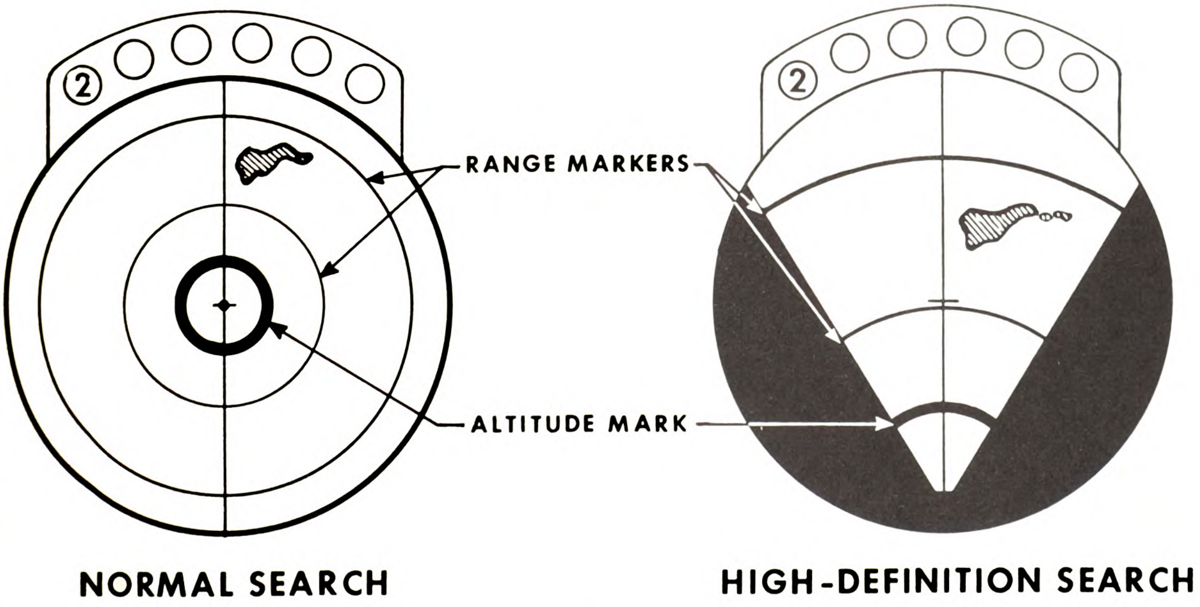
Equipment of this type must function under conditions of severe shock and vibration. The components, as a result, are mounted on specially constructed shock-insulating mounts. Filtering and shielding of the set are highly important because of the presence in the plane of other electronic equipment such as communication receivers and transmitters; and precautions must be taken to prevent interference between the various electronic and electrical systems.

General Description and Operational Features

Radar Set AN/APS-33 is designed to operate primarily as a search and navigation instrument with provision for beacon operation. Circuits and connections are also provided so that IFF and LAB (Low Altitude Bombing) equipment can be used. The set is intended for installation in larger aircraft such as patrol planes. It serves as a means of revealing the presence and location of surface vessels, aircraft, beacons, and other objects within the area covered in its operating range.

In the search function of the equipment, pulses of high peak power, and of very short duration are generated by the transmitter, and radiated in the form of a beam by a directional antenna. The beam is focused into a pattern a few degrees wide and is swept by movement of the antenna assembly either through 360 degrees or in smaller degree sectors. During the intervals between the transmitted pulses, the signals reflected from objects in the path of the beam are received by the same antenna used in transmitting and applied to a receiver. The antenna is switched alternately from transmitter to receiver by a duplexer.

Echo signals from targets are detected, amplified, and displayed on cathode-ray tube indicators, which are calibrated by range markers (circular lines which indicate the distance between the aircraft and the targets). The appearance of an indicator in normal and high-definition search is shown in figure 12-4.



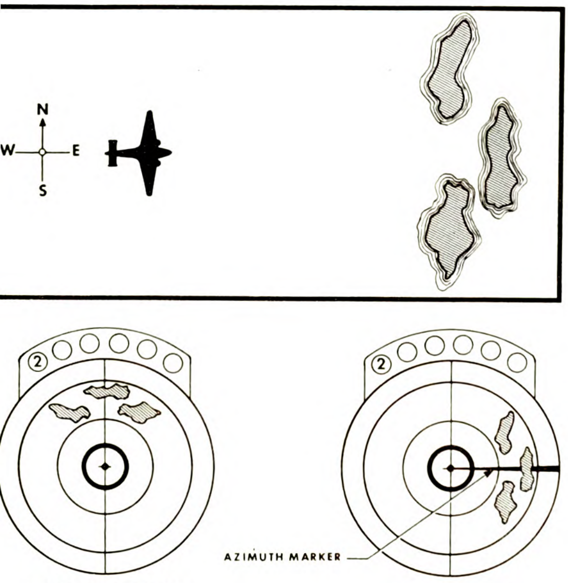
NORMAL SEARCH

HIGH-DEFINITION SEARCH

Figure 12-4.—Normal and high-definition search, AN/APS-33.

High-definition sector scan enables the erator to see a more detailed presentation the area scanned by the radar. The narrow rcles appearing on the screen are the range arkers. The wide circle is the altitude ark which indicates the altitude of the plane ove the earth's surface. At the top of the dicator face are six lights. One of the first ve is illuminated to give the separation in iles between adjacent range markers. The xth light, when illuminated, indicates that layed-sweep operation is in use.

The APS-33 provides both relative bearing d true bearing representation of targets. The o types of operation are shown in figure -5.



RELATIVE BEARING

TRUE BEARING

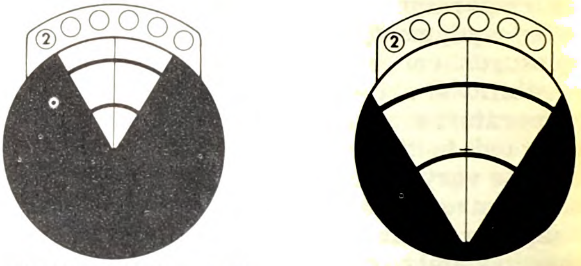
Figure 12-5.—Relative and true bearing indications.

In relative bearing operation, the indicator esentation is viewed as though looking dead ead from the cockpit. The scribed line on e indicator running through the top center of e display corresponds to the heading of the rcraft, and the targets are shown in relation the course.

In true bearing operation, the display reains fixed regardless of the aircraft's headg, and the pattern is read like a map with the p center of the display indicating magnetic rth.

The additional operational features of the PS-33 include depressed sector scan, tilt abilization of the antenna reflector, open center operation, altitude delay, and target discrimination operation.

The two types of sector scan presentation are shown in figure 12-6.



UNDEPRESSED SECTOR SCAN

DEPRESSED SECTOR SCAN

Figure 12-6.—Sector scan presentation.

The use of sector scan results in better definition. The operator has a choice of two antenna scanning speeds. The depressed sector scan is employed in relative bearing operation, and has the advantage that a greater area of the screen is used. This causes the target to appear larger.

Tilt stabilization is a process by which the tilt angle of the antenna reflector is held constant with respect to the true horizon at an angle selected by the operator regardless of changes in the attitude of the plane.

Tilt stabilization is especially valuable in maintaining targets on the indicator screen in rough weather. The general action of the stabilizing system is illustrated in figure 12-7.

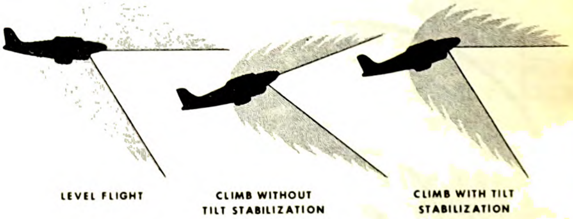
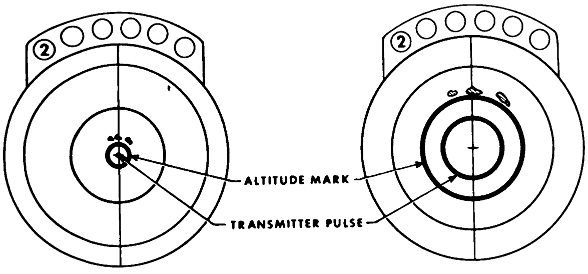

LEVEL FLIGHT
CLIMB WITHOUT TILT STABILIZATION
CLIMB WITH TILT STABILIZATION

Figure 12-7.—Tilt stabilization.

Open center operation, shown in figure 12-8, is used at short ranges to lessen the crowding of nearby targets. With this type of presentation, the images are spread out on the screen, allowing better identification of individual targets.

Altitude delay operation is provided for use at high altitudes to make available an otherwise wasted portion of the indicator screen. This type of operation gives a more realistic presentation of the area scanned.

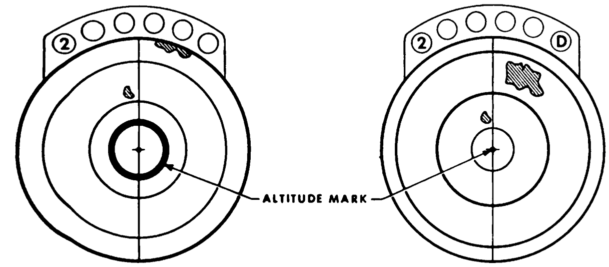


NORMAL

OPEN CENTER

Figure 12-8.—Open center operation.

In figure 12-9 in the normal screen presentation, an altitude of 5,000 feet is indicated by the wide, bright altitude mark near the start of the sweep. The portion of the screen below the altitude mark is wasted space. With altitude delay, the altitude mark is pulled down and coincides with the start of the sweep. The target which was only partially visible at the top of the screen has been moved down, making it completely visible.

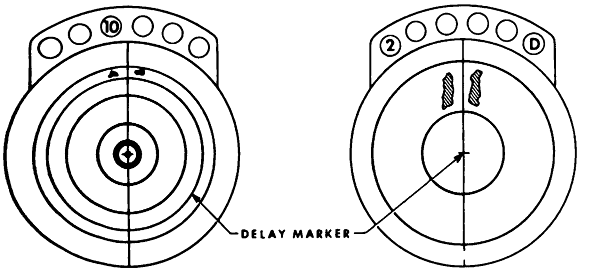


NORMAL

ALTITUDE DELAY

Figure 12-9.—Altitude delay operation.

Target discrimination operation, illustrated in figure 12-10 is used to provide an expanded view of a selected portion of the scanned area.



NORMAL
40-MILE RANGE
DELAY MARKER SET
AT 26-NAUTICAL-MILES

5TD
THE ENTIRE SCREEN
PRESENTATION NOW REPRESENTS
THE 5-NAUTICAL-MILE AREA
BEYOND THE DELAY MARKER

Figure 12-10.—Target discrimination operation.

With the APS-33, any 5- or 30-nautical-mile portion of the presentation may be selected for expanded display. The circular delay marker line is moved by rotating the delay knob in the control unit to select the particular 5- or 30-nautical-mile portion of the screen area, which the operator may wish to expand. In figure 12-10, the area between 26 and 31 nautical miles has been chosen for expansion to allow better identification of two distant targets. In the 5TD illustration in the figure, the entire screen represents the 5-nautical-mile area beyond the delay marker. This type of operation is accomplished by delaying and expanding the range sweep so that a ring-shaped area is collapsed into a small, solid circle.

During beacon operation of the set, pulses sent out by the transmitter are received by a beacon station. The pulses trigger the beacon transmitter which radiates coded signals. These are received by the radar set and displayed on the indicator to reveal the location of the plane with respect to the known location of the beacon station.

Control Unit

Control unit, C-289/APS-31 used with the AN/APS-33 equipment is illustrated in figure 12-11.

The functions of the controls are as follows:

1. Tuning: Tunes the receiver for both search and beacon operation.
2. Tilt: Controls the vertical tilt angle of the antenna reflector and adjusts this angle to the value indicated on the dial setting.
3. Scan: Controls antenna rotation. In the OFF position, the antenna remains stationary. Positions 1 and 2 provide sector scan (depressed and undepressed, respectively). In position 3 the antenna operation is 360-degree rotation. In LAB position, sector scan is employed and the antenna is controlled by the associated low-altitude bombing equipment.
4. Meter: The meter switch selects the proper meter range for measuring crystal current, magnetron current, or line voltage.
5. Range: The switch selects the desired operating range. The range is continuously variable from 5 to 60 nautical miles in search or beacon operation in accordance with the position to which the control is set. In the 120 position, the range is fixed at 0 to 120 nautical miles. In SEARCH 0-200 position, the range

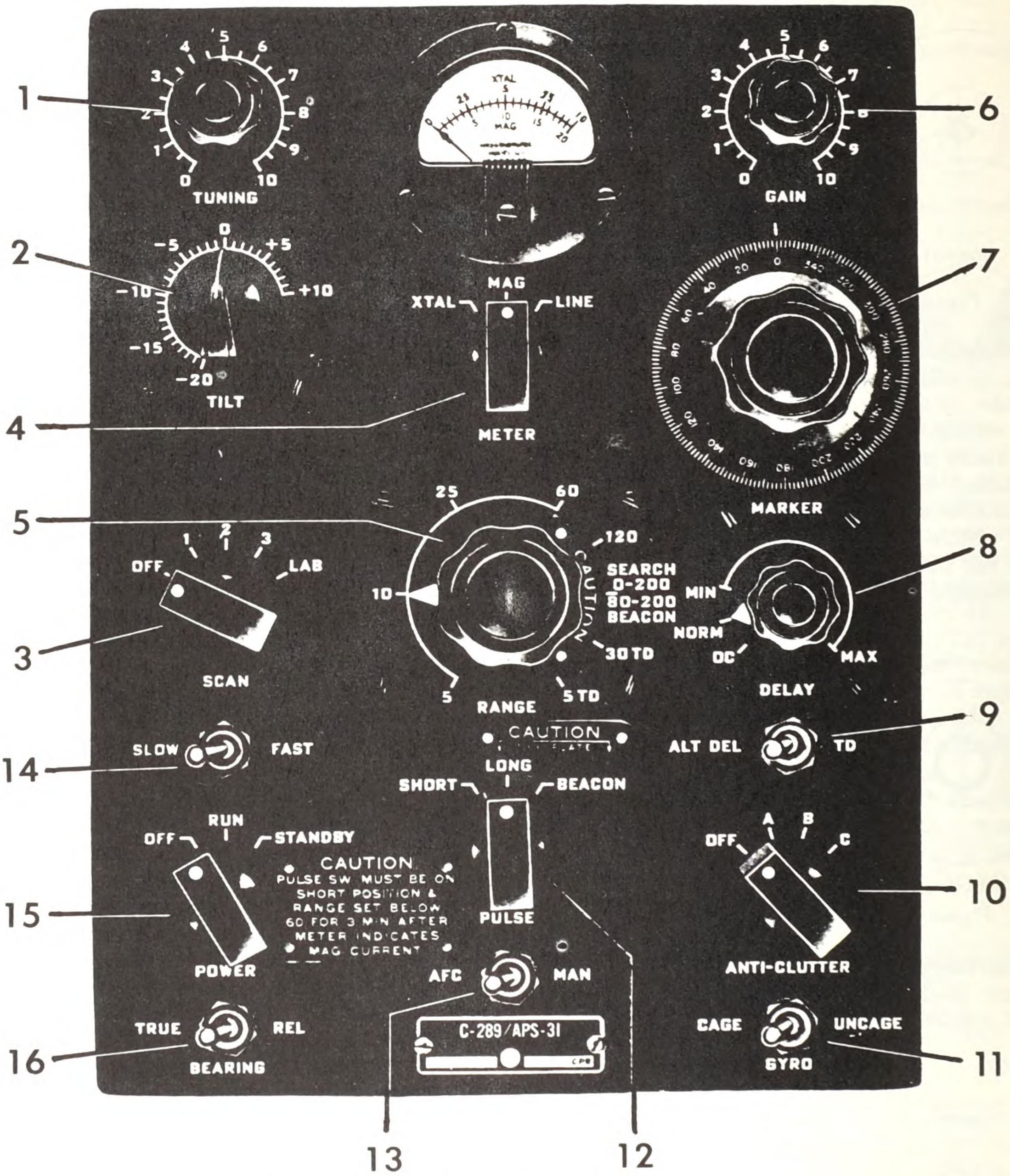


Figure 12-11.—Control unit C-289/APS-31 of Radar Set AN/APS-33.

is fixed at 0 to 200 nautical miles. In 80-200 BEACON position, the range is fixed at 80 to 200 nautical miles. In the 30TD position, a 30-nautical-mile section of the area scanned is presented as an enlarged view. In the 5TD position, a 5-nautical-mile area is presented as an enlarged view.

6. Gain: This dial controls the receiver gain.

7. Marker: The marker dial sets the position of the azimuth marker on the indicator allowing the bearing of a target to be determined. In sector scan operation, the dial sets the direction of the midpoint of the 60-degree sector being scanned.

8. Delay: In OC position, 1.5-nautical-mile open center operation is provided so that nearby targets may be more easily identified. No

delay is provided in the NORM position. The MIN to MAX position provides continuously variable delay from 0-5 or 0-200 nautical miles, depending on the position of the switch just below the delay knob.

9. Alt Del-TD: The switch setting determines whether the range of the delay knob is 0-5 or 0-200 nautical miles.

10. Anticlutter: This switch controls the anticlutter circuits which assist in identifying targets in the presence of interfering signals.

11. Gyro: The switch position determines whether the gyro is held in a fixed position (CAGE) or is used in the tilt stabilization system (UNCAGED).

12. Pulse: By means of the three positions of the switch, short pulses for high-definition search operation, long pulses for normal search operation, or beacon pulses can be selected.

13. AFC-Man: This controls the receiver tuning permitting either automatic frequency control or manual tuning control to be selected.

14. Slow-Fast: Governs the speed of rotation of the antenna reflector.

15. Power: The power switch disconnects all power from the equipment in the OFF position, applies power to the entire equipment in the RUN position (the transmitter high-voltage is applied automatically after the switch has been in RUN for three minutes), or applies all voltages except the transmitter high-voltage in STANDBY.

16. Bearing: In the TRUE position, the screen presentation is fixed with magnetic north appearing at the top center of the indicator. In the REL position, the top center of the screen represents the aircraft's heading and targets appear on the screen in positions relative to the course of the aircraft.

General Electrical Characteristics

The AN/APS-33 equipment requires both a-c and d-c primary power. About 9 amperes of alternating current are drawn at 115 volts. The a-c units are designed to operate over a frequency range of 380 to 1,600 cycles per second. The d-c requirements are 40 amperes at 27.5 volts.

The transmitter carrier frequency is 9,375 megacycles (plus or minus 55 mc.). In search operation, the receiver frequency is the same as the transmitter frequency; in beacon operation, the reception frequency is 9,310 megacycles. The receiver local oscillator operates 60 mc. below the transmitter frequency in search operations and 60 mc. below the frequency of the incoming signal in beacon operation.

The minimum RF output power of the transmitter for acceptable operation is 52 kilowatts. Three pulse duration values are supplied by the modulator unit as follows:

Short pulse: 0.5 microseconds.
Beacon pulse: 2.25 microseconds.
Long pulse: 4.5 microseconds.

The values of the pulse repetition frequency are: 800 pulses per second with short pulse operation, 400 p.p.s. with beacon pulse, and 200 p.p.s. with long pulse operation.

The antenna assembly contains a feed horn type of radiator and a parabolic reflector. The horizontal beam width is between 2.4 and 3.6 degrees at the half-power points, depending on the antenna unit used.

The antenna scans 360 degrees for conventional PPI operation and 60 degrees (plus or minus 10 degrees) in sector scan.

Two antenna scanning speeds are provided: Fast scan is about 24 r.p.m. in 360-degree rotation and 90 to 100 looks per minute in sector scan; the slow scan rate is 8 r.p.m. and 40 to 50 looks per minute in sector scan. The antenna reflector may be tilted upward or downward with respect to a plane approximately horizontal by means of a manually controlled knob on the control unit. The gyro stabilizer maintains the preset angle even when the attitude of the aircraft varies from the horizontal by as much as 30 degrees, either upward or downward, when the manual-tilt control is set at 0 degree.

Theory of Operation

The basic operation of the APS-33 radar set involves the development of superhigh-frequency signals to be transmitted, the radiation of these signals from the antenna system, reception of the energy reflected from target-objects, and the presentation of the received signals on the indicators. The pattern on the indicator screen is then interpreted to reveal the range and azimuth of the targets. The major components which are used in these actions are shown in simplified functional block diagram form in figure 12-12.

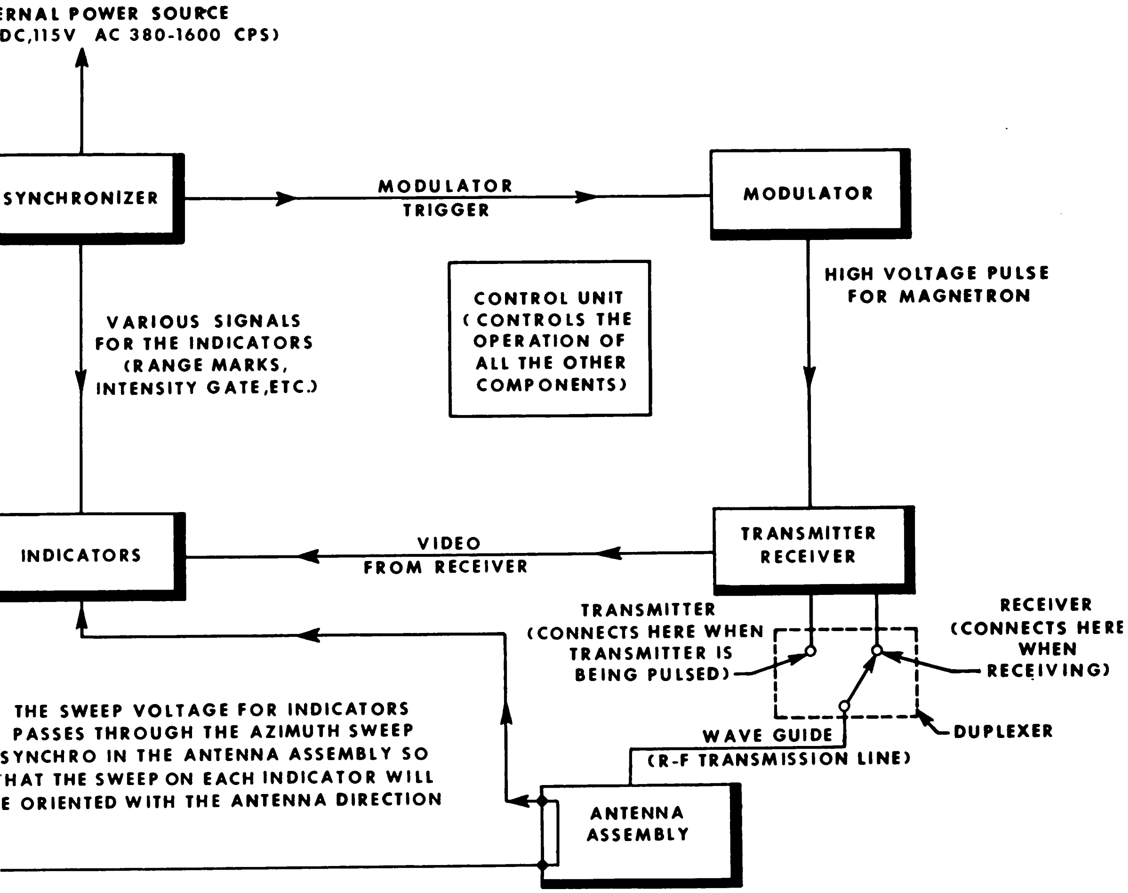

ERNAL POWER SOURCE
DC,115V AC 380-1600 CPS)
SYNCHRONIZER
MODULATOR TRIGGER
MODULATOR
HIGH VOLTAGE PULSE FOR MAGNETRON
CONTROL UNIT (CONTROLS THE OPERATION OF ALL THE OTHER COMPONENTS)
VARIOUS SIGNALS FOR THE INDICATORS (RANGE MARKS, INTENSITY GATE,ETC.)
INDICATORS
VIDEO FROM RECEIVER
TRANSMITTER RECEIVER
TRANSMITTER (CONNECTS HERE WHEN TRANSMITTER IS BEING PULSED)
RECEIVER (CONNECTS HERE WHEN RECEIVING)
DUPLEXER
WAVE GUIDE (R-F TRANSMISSION LINE)
THE SWEEP VOLTAGE FOR INDICATORS PASSES THROUGH THE AZIMUTH SWEEP SYNCHRO IN THE ANTENNA ASSEMBLY SO HAT THE SWEEP ON EACH INDICATOR WILL E ORIENTED WITH THE ANTENNA DIRECTION
ANTENNA ASSEMBLY

Figure 12-12.—Simplified functional block diagram AN/APS-33.

DEVELOPMENT OF THE TRANSMITTED SIGNALS

ynchronizer contains a circuit, the
rigger multivibrator, which generates
ous series of pulses used for timing
ɜ equipment. In this circuit, pulses
ıte of 200, 400, or 800 per second,
; on the range and the operating func-
ɜn, are fed to the fixed-delay circuit.
ced-delay circuit allows the firing of
mitter to be delayed until after the
ıe indicator sweep. Two time delays
ded: a short delay for normal opera-
h starts the outgoing pulse after the
portion of the sweep voltage has
nd a longer delay for open center
. (Open center presentation causes
ırgets to be displayed farther out
cator screen as shown in figure 12-8.)
leaving the fixed-delay circuit, the
ılse is amplified and shaped in the
trigger-shaper circuit of the modulator into a positive pulse somewhat rectangular in form. This pulse is applied to the grid of a thyratron tube through a cathode-follower circuit. The thyratron acts as a switch to discharge the pulse-forming network, a combination of inductors and capacitors. The network is charged in the interval between pulses, from the high-voltage power supply in the modulator. The abrupt discharge of the pulse-forming network gives rise to a high-amplitude pulse with a precisely controlled time duration. A cable connects the pulse to the receiver-transmitter where it is passed through a transformer and stepped up to approximately 15,000 volts before it is used to fire the transmitter magnetron.

The magnetron oscillates for the duration of the modulator pulse, sending superhigh-frequency energy at high power through the waveguide to the antenna. On the way, the transmitted pulse actuates the duplexer.

The duplexer acts as a switch, connecting the transmitter to the antenna during transmission, and to apply the reflected target signals to the receiver during reception. The switching components of the duplexer are the TR and ATR tubes.

The TR tube is located in the waveguide system at a point one-quarter wavelength from the path of the transmitted pulse. Ionized by the outgoing pulse, the TR box effectively short circuits the input to the receiver and places a high impedance one-quarter wavelength away in parallel with the waveguide so that no shorting of the main pulse occurs. The ATR tube fires at the same time and has the effect of making the main waveguide wall continuous so that the pulse emerges with little loss.

RADIATION SYSTEM OPERATION

The superhigh-frequency energy is conducted through the directional coupler to the horn radiator in the antenna assembly and then into a reflector which releases a narrow beam into space. In the vertical plane, the beam is somewhat fan shaped, having the cosecant-squared pattern; and in the horizontal plane, the beam is from 2.4 to 3.6 degrees wide (depending on the antenna assembly in use). The scanner (the radiator and reflector) is rotated either continuously in one direction or back and forth, causing the radiated beam of energy either to sweep the area around the aircraft or to sweep a selected 60-degree sector. Continuous rotation of the scanner results in the map-like presentation of the PPI scan.

The operator can set the angle of the antenna scanner with respect to the horizontal plane and so adjust the radiated beam of energy to cover desired areas. The angle of the scanner is set by means of the manual tilt control on the control unit. The control setting governs the action of a system containing several synchro units and a servo amplifier which supplies signal voltage to the tilt-torque motor. This motor swings the scanner to the desired angle selected at the control unit.

Once the tilt angle has been selected, the tilt stabilization system maintains the scanner angle and compensates for pitch of the aircraft. The central part of the tilt stabilization system is a gyroscope which remains on a constant vertical axis when the plane pitches and rolls. Within the gyroscope unit are synchros which develop signals corresponding to the instantaneous attitude of the plane. These signals are applied to the system of synchros and the servo amplifier which governs the tilt motor so as to keep the scanner at the chosen angle.

A second type of stabilization (azimuth stabilization) is employed in which the display on the indicator is stabilized instead of the antenna assembly. The use of azimuth stabilization permits true bearing operation, in which the top of the indicator represents magnetic north regardless of the heading of the plane. With azimuth stabilization, when the heading of the plane changes, signals from the master indicator of the aircraft's electric compass are applied to a synchro in the antenna assembly. The synchro applies a signal to the true bearing amplifier. The output of the amplifier controls the operation of a motor which adjusts the stator of the azimuth sweep synchro. This synchro corrects the pattern on the indicator to compensate for changes in the aircraft heading to maintain the customary map pattern in which north is represented by the top of the display. When azimuth stabilization is not in use, the top center of the display corresponds to the heading of the aircraft. In this type of operation, a signal from a synchro (the zero-set synchro) is applied to the true bearing amplifier input instead of the electric compass signal.

RECEPTION OF REFLECTED SIGNALS

When the pulse radiated from the antenna system strikes an object, a portion of the energy is reflected. The antenna rotates very slowly in comparison to the speed of the beam, and some of the reflected energy is picked up by the reflector of the antenna system and directed through the horn radiator and the waveguide into the duplexer from which it is applied to the receiver.

During beacon operation, the signal received is not reflected from an object, but is transmitted from a beacon station transmitter which is triggered by the pulse radiated from the radar set.

During reception, the ATR tube in the duplexer prevents the energy received from being dissipated in the magnetron cavity and directs it into the receiver mixer chamber. The TR tube remains de-ionized, removing the short circuit from the input to the receiver. The incoming signals are mixed with the output of the receiver local oscillator to provide the IF signals. After several steps of IF amplification, the signals are applied to the second detector from which they emerge as video variations. These are further amplified after passing through a process of limiting and are then fed to the indicators.

Two local oscillators are employed in the receiver—one for search and one for beacon operation. The local oscillator tubes are 2K25 reflex klystrons. The cathodes of the tubes are grounded, and the resonant cavities are operated at 300 positive volts. The repeller voltage can be varied in negative potential between 100 and 200 volts; and by this means, the frequency of the local oscillators is adjusted. The adjustment can be made either manually or by use of the automatic frequency control system. When automatic frequency control is employed, the search local oscillator is held at 60 megacycles below the magnetron frequency during search operation, and the beacon local oscillator is held at 60 mc. below the frequency of the incoming signals in beacon operation. The anticlutter circuits in the receiver reduce interference from sea or ground echoes, from rain squalls, and from jamming signals; a "stretching" circuit is used during beacon operation to make the received signals more discernible.

PRESENTATION CONTROL CIRCUITS

As indicated in the block diagram of figure 12-12, the indicators are supplied with various signals in addition to the video information. These include the sweep voltage, the range marker pulses, voltage for producing the azimuth marker, and the intensity gate which unblanks the cathode-ray tubes to allow signals to become visible on the screens. These voltages are generated in circuits contained in the synchronizer which also includes the circuits which produce the fixed and variable time delay intervals used in open center, target discrimination, and altitude delay operations.

The time base or sweep for the indicators is a radial luminous line whose length is proportional to time, and consequently to range. The sweep circuit and compensating gate circuit employ 21 tubes to develop voltages and currents of the proper waveforms to provide a linear time base, or sweep. The sweep circuit generates voltages which produce linearly rising currents in the indicator deflection coils. The compensating gate circuit produces rectangular waves of voltage which are at all times equal in area to the areas under the corresponding sweep waveforms and opposite to them in polarity. The two waves are combined in the driving circuits for the cathode-ray tube deflection coils. The resultant waveform insures that the sweep is linear and also that it starts at the same point each time. Before reaching the deflection coils, the sweep signals are fed through the azimuth sweep synchro in the antenna assembly for synchronization with the rotation of the scanner.

The azimuth marker, a bright radial line on the screen, is produced by voltages generated by an oscillator in the synchronizer. The oscillator is triggered by a pulse which coincides with the null of a signal originating in the azimuth marker synchro on the antenna assembly. When the scanner passes a point selected by the setting of the marker dial on the control unit, the oscillator is triggered, and the azimuth marker appears on the screen. By use of the control dial, the marker may be made to intersect a target image and the relative bearing of the target can then be read directly from the control dial. In sector scan operation, the signals which control the marker oscillator are such that the marker always appears in the center of the sector being scanned.

Intensity gating is controlled by either the sweep gate circuit or the range marker control circuit. The intensity gate circuit contains a cathode follower and a diode clamper tube. During normal operation, when range markers start, a pulse from the range marker gating circuit operates the intensity gate which unblanks the indicator to allow the range markers and other signals to appear on the screen. During target discrimination operation, the intensity gate circuit is controlled by the circuit which controls the sweep.

A range marker generator in the synchronizer develops equispaced pips which, when applied to the indicators, mark off the screens in luminous arcs graduated in nautical miles. Depending upon the range in use and the type of operation, five different sets of range markers are automatically supplied to the indicators for range measurement in intervals of 2-, 5-, 10-, 20-, and 50-nautical miles. The range pips are developed in a modified Hartley circuit used as a gated oscillator which generates oscillations with periods corresponding to the distance between the range markers. A trigger voltage from the modulator trigger circuit in the synchronizer is applied to the range marker gating circuit to actuate a switch tube which allows the oscillator to operate. The control

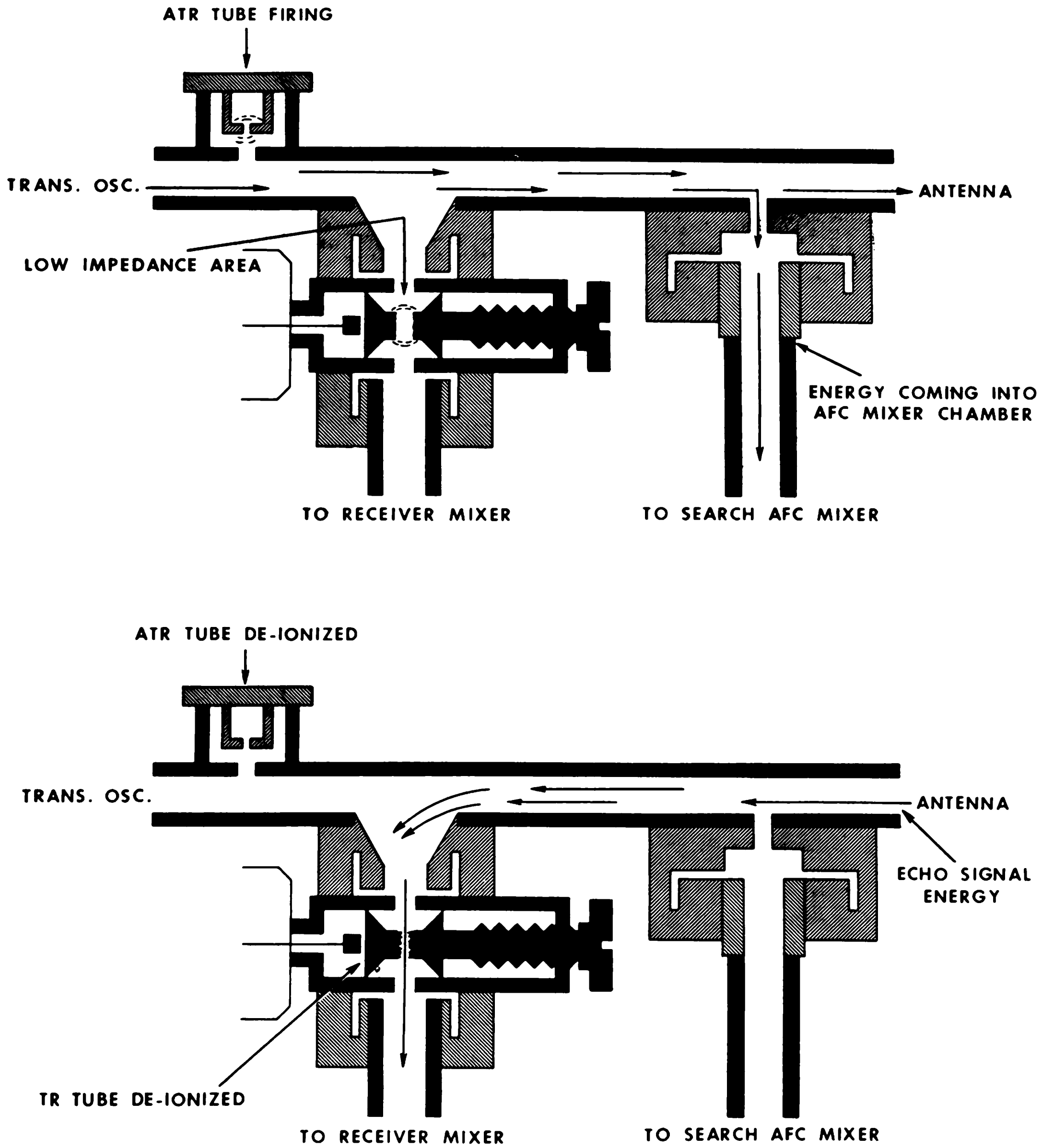


Figure 12-13.—Duplexer action.

of the range marker oscillator by the modulator trigger pulse insures that the range marker circuit operates in synchronism with the firing of the transmitter.

THE DUPLEXER

The duplexer which contains the TR and ATR tubes functions as an automatic switch, alternately transferring the waveguide from the receiver input to the transmitter as each pulse is sent out. The basic action of the duplexer in transmitting and receiving is indicated in figure 12-13.

The tubes are gas-filled resonant cavities which are coupled to the waveguide by glass-covered windows, or irises. When the transmitter is fired, the outgoing pulse causes the gas in the tubes to ionize and arc-discharge to take place in the cavities. In this condition, the ATR tube conducts the magnetron pulse in the main waveguide, and the TR tube excludes it from the input to the receiver. During reception, the weak echo signals do not cause ionization of the switching tubes; the ATR tube prevents the returned signals from being applied to the magnetron cavity, and the TR tube allows signals to enter the receiver input.

The ATR cavity is mounted on the broad side of the waveguide, and the TR box is coupled to the narrow side of the guide. This type of mounting causes the ATR to act as an equivalent series element and the TR to appear as a parallel equivalent element. The relation of these elements to the magnetron and the receiver can then be represented by the equivalent circuit shown in figure 12-14.

An outgoing pulse from the magnetron ionizes the gas in the ATR tube, and in this condition the tube allows the power to flow toward the antenna with little loss. The TR tube in the line leading to the receiver also ionizes and short-circuits the receiver input, thereby protecting the delicate components in the receiver from burn-out. The equivalent section containing the TR tube resembles a quarter-wave parallel stub which is short-circuited by the arc-discharge. It places high impedance in shunt with the line and causes very little interference to the transmitted pulse while largely preventing the transmitter output from entering the receiver.

At the completion of the outgoing pulse, the breakdown in the tubes ceases and the system is ready to receive echo signals from targets. The impedance at the terminals leading into the magnetron is extremely high, since when de-ionized, the ATR tube is essentially an open circuit in series with the line with the open located one-half wave from the T-junction. In the direction of the receiver, the incoming signals see a matched line when the TR box is de-ionized, and the echo signals flow into the receiver input.

The ATR tube is a rectangular cavity closed at one end by a metal flange and at the other by the glass-covered coupling window. The opening at the lower face of the tube is placed over a hole in the waveguide so that the face of the tube is flush with the surface of the guide. The entire ATR tube is about one wavelength long and is mounted in a holder on the broad side of the guide. It is tuned at the factory by positioning a shorting partition inside the cavity to a point about one-quarter wavelength from the coupling window. The tuning adjustment is then sealed, making the tube a fixed-tuned element. During arc-discharge, the breakdown occurs across the inner face of the glass window, causing the opening to appear as a continuous surface. In the deionized state, the cavity is equivalent to a shorted quarter-wave stub in series with the section of waveguide leading to the magnetron.

The TR tube, a 1B24, is a gas-filled resonant cavity containing two cone-shaped main electrodes and a keep-alive electrode. The latter is used to ionize the gas to a point just below breakdown so that a very small portion of the transmitted energy is needed to fire the gap between the main electrodes. The TR cavity is tuned to the frequency of the search pulse; coupling into and out of the cavity is made by glass-covered resonant openings.

THE INDICATOR ASSEMBLY

The indicator ID-162/APS-31, which is shown in simplified block diagram in figure 12-15, contains the cathode-ray indicator tube, the video amplifiers, a focusing magnet, the deflection yokes, and the range marker lights.

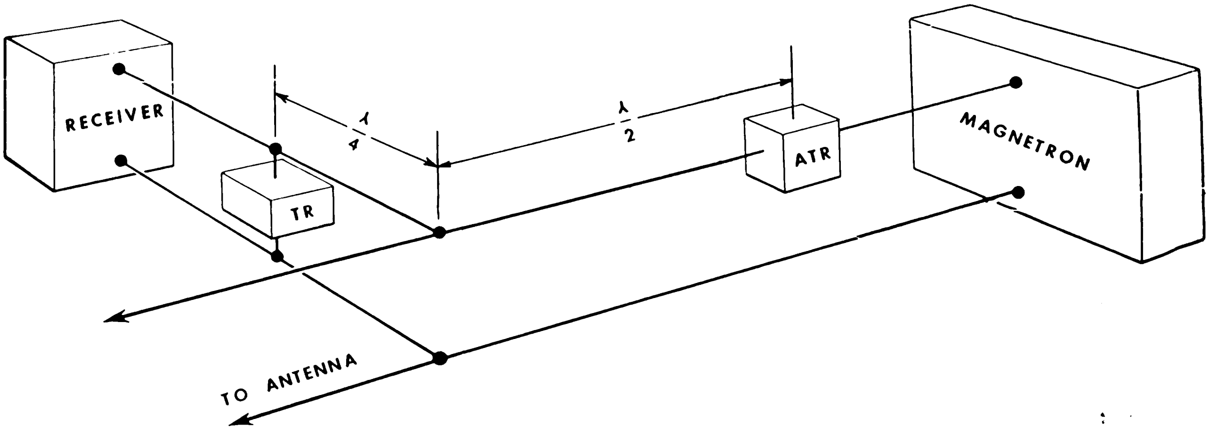


Figure 12-14.—Duplexer equivalent circuit.

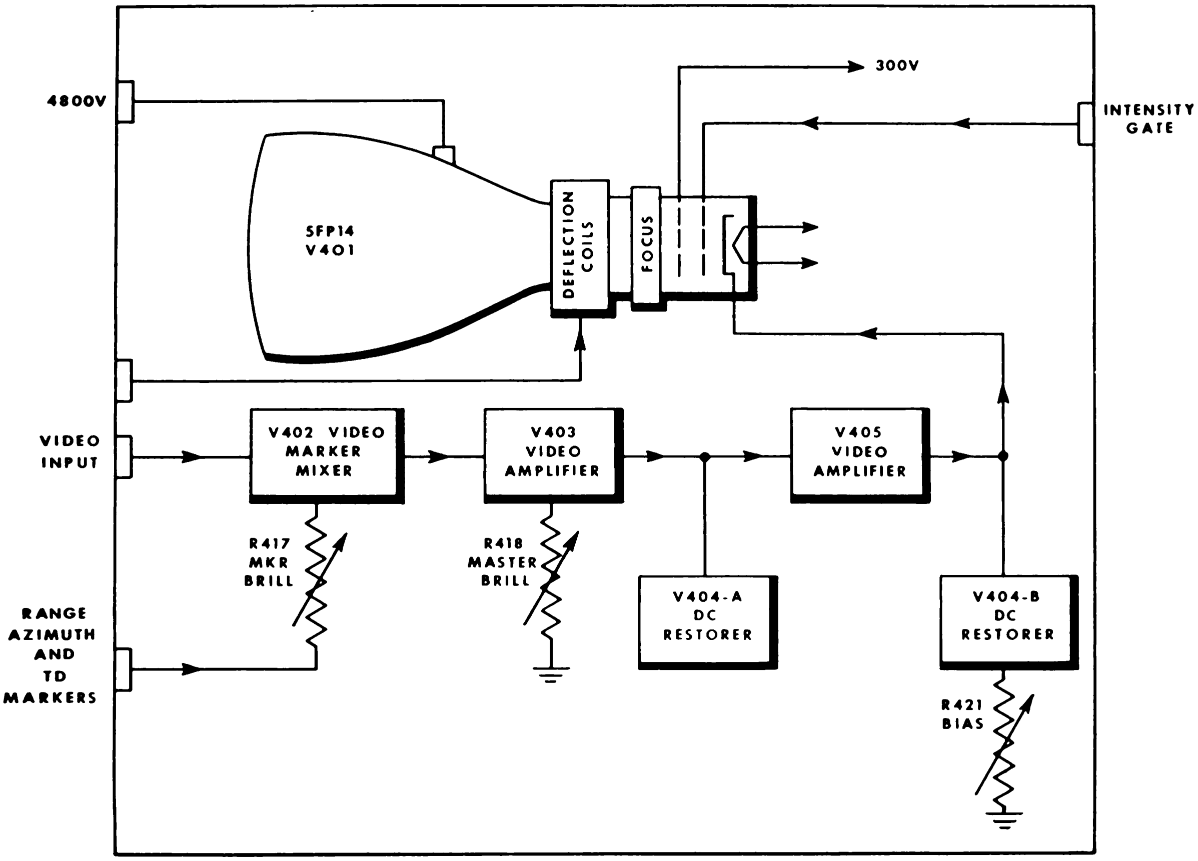


Figure 12-15.—Indicator block diagram.

The indicator tube on which the radar display is presented is a cathode-ray tube. Magnetic focusing of the electron beam is provided by means of a permanent magnet surrounding the neck of the tube. Focusing adjustments are made to regulate the sharpness of the sweep line appearing on the screen by use of a focus control mounted on the tube housing. The focus control varies the magnetic field of the permanent magnet by means of an adjustable armature.

Magnetic deflection of the electron beam is employed. The deflection yoke to which the sweep signals are applied is attached electrically to the stator windings of a two-phase synchro in the antenna assembly. The yoke surrounds the neck of the cathode-ray tube and has two a-c coils and two d-c coils. The a-c coils are wound 90 degrees out-of-phase and deflect the electron beam horizontally and vertically when supplied with voltage from the sweep synchro. The d-c coils are wound in the slots containing the a-c windings; one of the d-c coils produces vertical deflection of the beam to give depressed sector scan display on the indicator. The other d-c winding is called the roll coil and is provided for use with associated equipment but is not in use in Radar Sets APS-33 and APS-33A.

A positive potential of 4,800 volts is applied to the intensifier anode of the CRT from a supply in the modulator. The other indicator tube potentials originate either in the synchronizer or in the video circuits. The accelerating anode of the tube is operated at positive 300 volts, the control grid is at ground potential when the tube is unblanked, and the cathode is biased positive with respect to ground.

The video signals which produce the target or beacon images on the scope are applied to the indicator assembly from the receiver through a coaxial cable. As shown in figure 12-15, these signals are coupled to the video mixer (*V*402), a twin triode. One grid of *V*402 is supplied with range marker signals from the synchronizer. The input of the range marker section of the mixer contains a potentiometer, the marker brilliance control (*R*417) by means of which the brilliance of the markers visible on the indicator screen is regulated. The plates of both halves of the mixer sections contain a common load element, and the negative marker signals and the video voltages both appear in the output which is coupled to the grid of *V*403, a video amplifier. The cathode circuit of *V*403, contains a variable resistor, *R*418, which is used as a master control for regulating the brilliance of both markers and the video target images on the scope screen.

The indicator tube cathode is given a positive bias by the connection to the potentiometer, *R*421. The d-c restorer, *V*404B, conducts only when the video signals applied attempt to drive the cathode more positive than the value of the bias voltage. As a result of the diode action, the cathode signals consist entirely of negative-going swings starting at the bias voltage level. These vary the intensity of the electron stream to produce the target images. Adjustment of the bias control determines the unblanking level of the indicator tube.

As indicated in figure 12-15, the intensity gate signal is applied to the control grid of the indicator tube. The unblanking gate is supplied by the synchronizer and is a pulse which swings from negative 40 volts to zero.

Aircraft Early Warning

The AEW system serves to extend the radar horizon of search radar equipment by means of a relay link. A high-powered airborne search radar collects radar data and relays it to monitoring units. The monitoring units may be ship-board, land-based, or airborne installations. The relay link extends the area of radar coverage in any one direction by the distance over which the relay link is effective. In addition, the area covered by shipboard or land-based radar is enlarged since the airborne unit operates at a high altitude with a greatly extended horizon. The airborne radar used for collecting the radar information is characterized by very high power and a large antenna in order to obtain maximum range. The maneuverability of the plane in contrast to the slow-moving ship increases the amount of data which can be assembled and used at the station receiving the relayed data.

All-Weather Attack Radar

Special types of radar are used in all-weather fighters and attack bombers which are extensions of the basic search equipment. A typical installation of this kind performs the following functions: Detection and location of aircraft; gun aim indication for the firing of fixed guns; detection and location of ships and other objects on the surface of the sea; mapping of land-water contours as a navigational aid; and detection (and location) of beacon stations for the purpose of homing and navigation.

All-weather fighter radar is similar to general search equipment in its basic principles of operation and in the types of major components used. Since this equipment is used in tactical actions against enemy aircraft, it employs types of presentation which show the altitude of the target with respect to the fighter plane. A high value of PRF (pulse repetition frequency) is used; and special devices for suppressing clutter, unwanted echoes from sea or land, are important parts of the equipment. The minimum range at which targets can be detected must necessarily be of a low value in this type of radar, with typical values ranging from 100 to 150 yards.

The usual all-weather fighter equipment differs from other types in the variety and kinds of scanning patterns provided. The antenna assembly is designed to make several sorts of motion and can sweep the radar beam over the search area in a number of different ways. These types of scanning patterns include search, intercept, acquisition, and aim scans.

SEARCH SCAN

This operation is employed in detecting and locating land, sea, or air targets, and in mapping contours at various ranges. It is not used for location of aircraft at large angles of elevation.

The radar beam is sometimes distorted by a beam deflector at the antenna to give a downward coverage, and the resulting pattern is swept in sectors of either wide or narrow angle, as shown in figure 12-16.

The indicator for displaying the radar data gathered by this scan in many installations is the B-type of presentation. This is a square, map-like display in which the horizontal position of the indicator trace is synchronized with the direction in which the antenna points. The position of the target image on the scope measured horizontally from the vertical center line indicates the bearing of the target. A vertical sweep of the cathode-ray beam occurs with each pulse; hence, the position of the image measured vertically from the lower edge of the screen indicates the range. The appearance of the B-scope and the relation of the trace to the antenna direction are shown in figure 12-17.

INTERCEPT OPERATION

Intercept operation is used for detecting and locating enemy aircraft and for making tactical approaches on them. The range of detection is usually about 20 miles or less. In some radar systems, this operation involves a complex type of scan in which the antenna scanner revolves rapidly in a way that causes the radar beam to search a solid angle by tracing out a spiral. After an increasing spiral has been described and the diameter reaches a maximum value, the beam then traces another spiral path which diminishes to the center. Two values of search angle are usually provided as shown in figure 12-18. The radar beam in spiral scan is in the form of a narrow ray about 5 degrees in diameter.

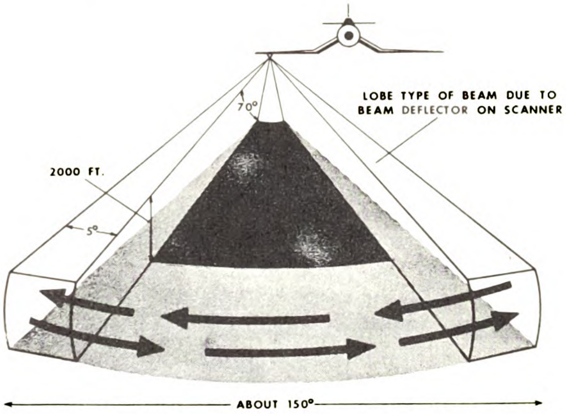


Figure 12-16.—Search scan.

The information gathered by spiral scanning is often presented on a modified B-scope called a "double-dot" display. The screen shows azimuth, range, and elevation of the target aircraft. Two bright dots appear for each target. One of the dots is the usual range-azimuth image which appears on the B-scope during search operation. About one-eight inch to the right of the target dot is a second dot which indicates the relative elevation of the target. The elevation dot is alongside the target dot when the target is in the line of flight of the observer. It is higher or lower on the screen when the target is above or below the observer.

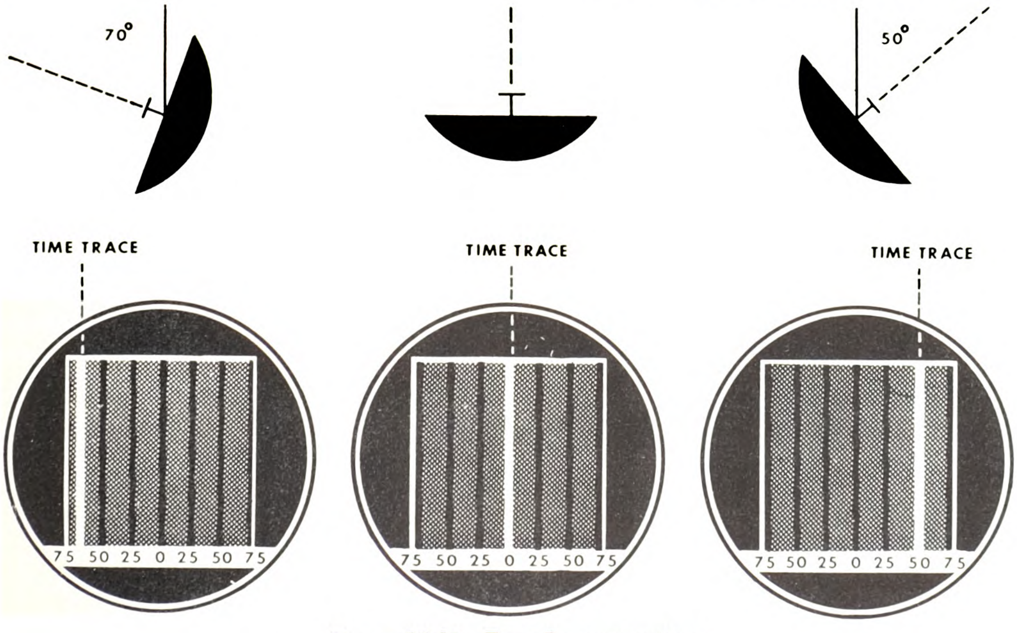


Figure 12-17.—Type B presentation.

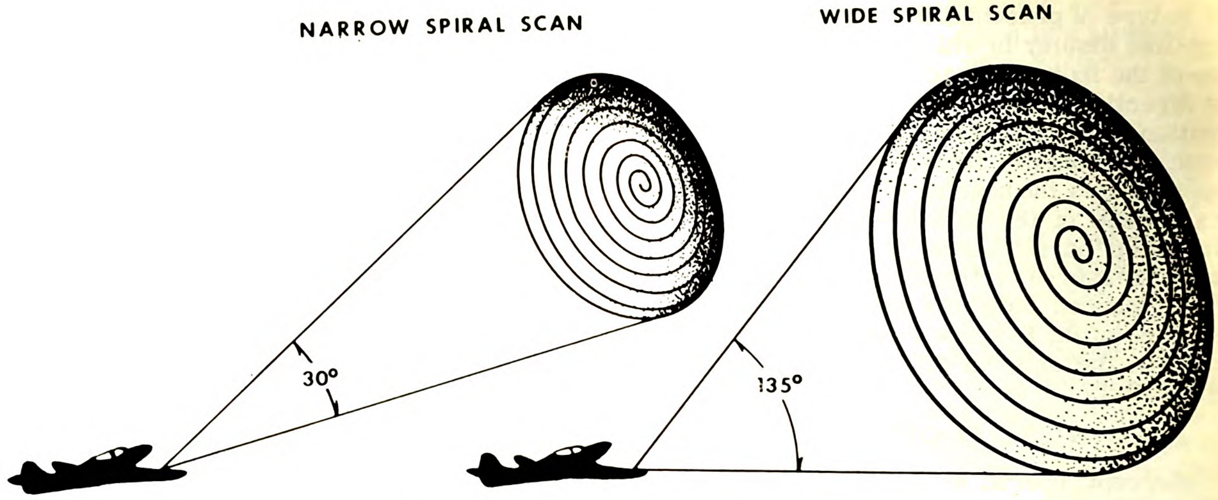


Figure 12-18.—Space diagram of spiral scans.

In the newer intercept radars, the type f antenna scan used is called a "Palmer can" because it combines the motion of small, rapidly spinning cone along with slower left-right motion, and therefore esembles the old circular type of pen-nanship exercise popularized by Palmer nany years ago. The advantage of this ype of scan over the spiral is that the azinuth and elevation coverage can be varied ndependently, and a wider angle in azinuth than in elevation is usually desired. he usual type of display is a standard B-cope with some device to display antenna lt for elevation information.

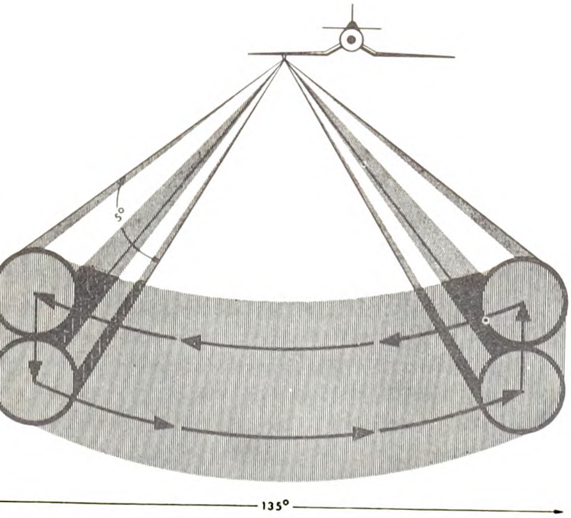


Figure 12-19.—Acquisition scan.

ACQUISITION SCAN

This operation is used for the detection and location of aircraft targets at greater ranges than can be expected in search or intercept operations. A typical scanning pattern for older radars is shown in figure 12-19 in which the antenna is moved from side to side, directing a narrow beam in a sector of about 135 degrees. At the two extremes of the sweep, the beam is displaced approximately 5 degrees in the vertical plane so that the center line of the ray traces a rectangle.

Since the radiated energy is concentrated into a narrow ray and is not distorted or fanned downward, the intercepted targets within the field of view return strong echo signals. Targets which are not discernible in search operation can be detected with acquisition scan.

GUN AIM PRESENTATION

Several types of gun aim displays are used in all-weather fighter radar equipment. One of these, the G presentation, is shown in figure 12-20. The scope is used for aiming the plane's fixed guns and has an appearance similar to an optical gunsight.

On the G-scope, target azimuth is indicated by the image position along the horizontal axis and elevation is represented on the vertical axis. The target appears as a bright spot with wings. The span of the wings represents the range. With the dot centered at the intersection of the inscribed cross hairs, and the wings just touching the vertical marks, the target is

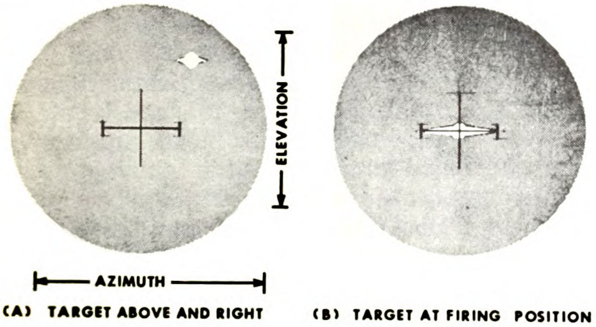


Figure 12-20.—Type-G display, or gun aim presentation.

at the point of convergence of fire, usually about 250 yards. If the wings are of lesser width, the distance is beyond the gun-convergence range. When the wingspan is greater than the distance between the lines, the enemy plane is closer than the open-fire point. The position of the winged dot up or down, right or left, gives the position of the target relative to the fighter plane.

A conical antenna scan is used with this type of presentation. The antenna reflector is rotated about a center point so that the radiated beam searches a cone of space forward of the aircraft. The diameter of the cone is twice the beam diameter, and the angle at the apex may be 8 to 12 degrees. Another and more popular variation is to show the range on a separate line or trace on the same display, retaining the dot for the up-down, right-left information.

IFF System

The primary purpose of an IFF system is to provide an accurate and rapid means of determining the friendly or enemy character of objects detected by radar. Some means of identifying the target is necessary because the radarscope shows all objects in much the same way with the images differing only in amplitude and without identifying detail.

The basic operation of an IFF system and the essential units involved are shown in figure 12-21.

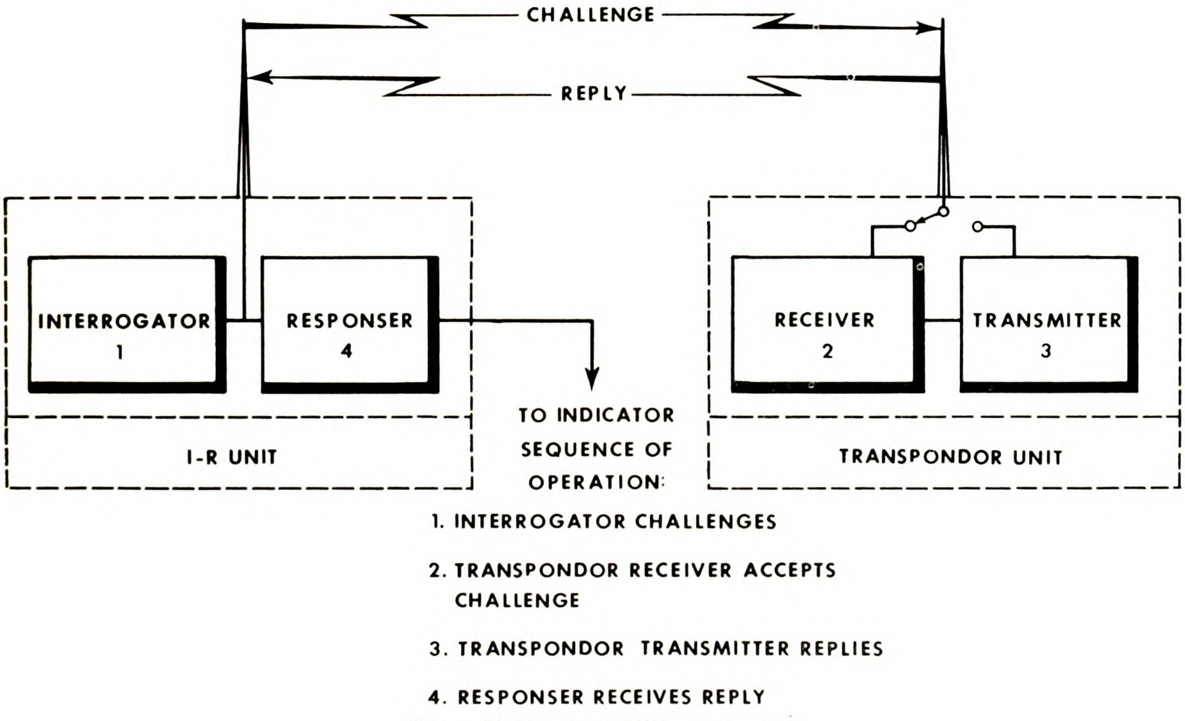

CHALLENGE
REPLY
INTERROGATOR
1
RESPONSER
4
RECEIVER
2
TRANSMITTER
3
I-R UNIT
TRANSPONDOR UNIT
TO INDICATOR
SEQUENCE OF OPERATION:
1. INTERROGATOR CHALLENGES
2. TRANSPONDOR RECEIVER ACCEPTS CHALLENGE
3. TRANSPONDOR TRANSMITTER REPLIES
4. RESPONSER RECEIVES REPLY

Figure 12-21.—Basic IFF operation.

The elements of the system consist of the interrogator, the transpondor, and the responser. The interrogator is a pulse-type transmitter which acts as the challenger. When a radar operator sights an unidentified target on the radar, he sets the interrogator in operation and it emits coded challenging pulses.

The challenge is received by the transpondor which is a receiver-transmitter, also of the pulse type. Upon receiving the proper challenge, it automatically transmits a coded identifying reply. The transpondor is kept in a standby condition and transmits only when the proper interrogating signal is received. Almost all aircraft and ships of the armed forces carry transpondors since this is the unit which provides identity when challenged.

The responser is a receiver which accepts the reply to the challenge, the coded signal sent out by the transpondor. The replies are then presented on an indicator which may be either that of the associated radar set or a separate scope. In airborne equipment, the interrogator and responser are usually contained in the same housing and are known as the Interrogator-Responser, or I-R unit. Only those aircraft such as patrol planes or all-weather fighters whose mission requires that unknown radar targets be identified immediately carry I-R units.

Radar Beacons

Radar beacons, or racons, are pulse repeater stations which are used as navigational aids. The beacon receives pulses from airborne radar transmitters and sends coded identifying pulses in reply. Transmissions are made from the beacon station with nondirectional antennas which provide equal signal coverage in all directions. The beacon reply is displayed on the radarscope of the aircraft to reveal the range, azimuth, and identity of the beacon.

Beacon stations are usually located on land with their positions clearly indicated on charts, although sometimes they are carried on ships and aircraft. The equipment consists of a pulse-type receiver-transmitter called a TRANSPONDOR. The receiver does not respond to ordinary search radar transmissions but only to pulses of a certain length (between 2 and 3 microseconds for the microwave frequencies). This prevents unnecessary transmission since the station operates only when interrogated by a search radar working on beacon operation. The beacon reply is sent on a frequency different from that of the interrogating radar pulse. To receive it, the receiver of the aircraft radar must be retuned from the normal search frequency to that of the racon signals. (This tuning is accomplished quickly and easily from the radar control panel when the set is switched to beacon operation.) Since the radar receiver is then set to a frequency different from that of the outgoing radar pulse, no echoes from targets are displayed on the radar screen and only the beacon pulses are visible.

Beacon operation permits observation of targets whose positions are fixed and known. When more than one beacon station is in the area scanned, several beacon signals can be displayed simultaneously on the scope. A typical PPI display of two beacons is illustrated in figure 12-22.

The beacon signals reveal the range, bearing, and identity of the beacon station. In the figure, the range is determined by measuring the indicated distance to the pulse nearest the center of the screen. Negligible delay is involved in the beacon response, and the inside pulse represents the first signal returned in answer to the radar interrogation.

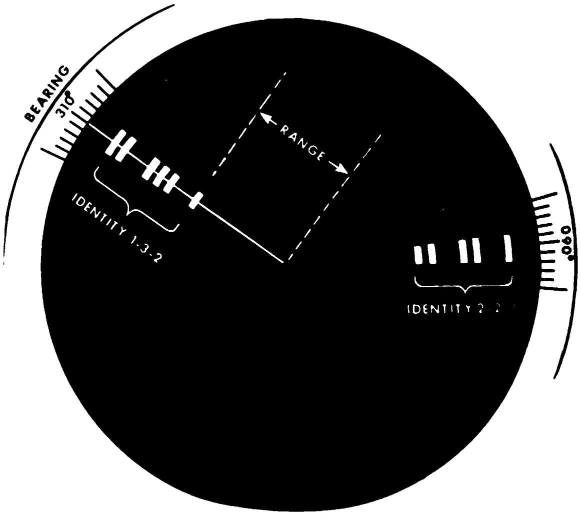


Figure 12-22.—Beacon signals on PPI display.

The azimuth, or bearing, of the station is determined by the position of a line bisecting the beacon signal on the scope, as shown in figure 12-22, for the signal at 310 degrees of relative bearing. The width of the signal on the screen depends primarily on the antenna beam width of the scanning radar and does not depend on the azimuth of the station.

To establish identity, the beacon signals are range-coded. That is, a series of two to six pulses is transmitted in a group with short time intervals between. On the radar screen the pulses appear separated by range spaces. The station is identified by counting the number of pulses in the group, reading from near to far range. In figure 12-22, the code of the beacon signal at 310 degrees is 1-3-2 while the group at 90 degrees is 2-2-1. The assigned codes and the positions of land-based racons can be found from aircraft navigational charts.

Beacon transpondors are installed on many aircraft carriers for homing purposes and are carried in some aircraft. The code assignments of the mobile stations are changed at intervals and must be determined prior to flight by reference to the proper classified publications.

Radar Altimeters

Radar altimeters are used to measure absolute altitude, the distance separating the aircraft and the terrain beneath it. The principal function of this radar device is range measurement in which the target is the land or sea surface below the plane. And as in other examples of radar ranging, distance is determined by making indirect measurements of time. The time interval of significance is that required for the transmitted signal to reach the ground or sea below the plane and to return.

Since its operation does not depend on atmospheric data, the radar altimeter is free from some of the disadvantages of barometric altimeters. It requires no recalibration when flying from one pressure area to another; and it removes the necessity for learning the terrain altitude from navigational maps in order to determine the terrain clearance of the aircraft.

Two basic types of radar altimeters are in use. One of these is a continuous-wave, frequency-modulated system. The other is a pulse device in which the operation is similar in principle to most search radar sets. The CW, FM altimeter system is best illustrated by the AN/APN-22 equipment. (See fig. 12-23.)

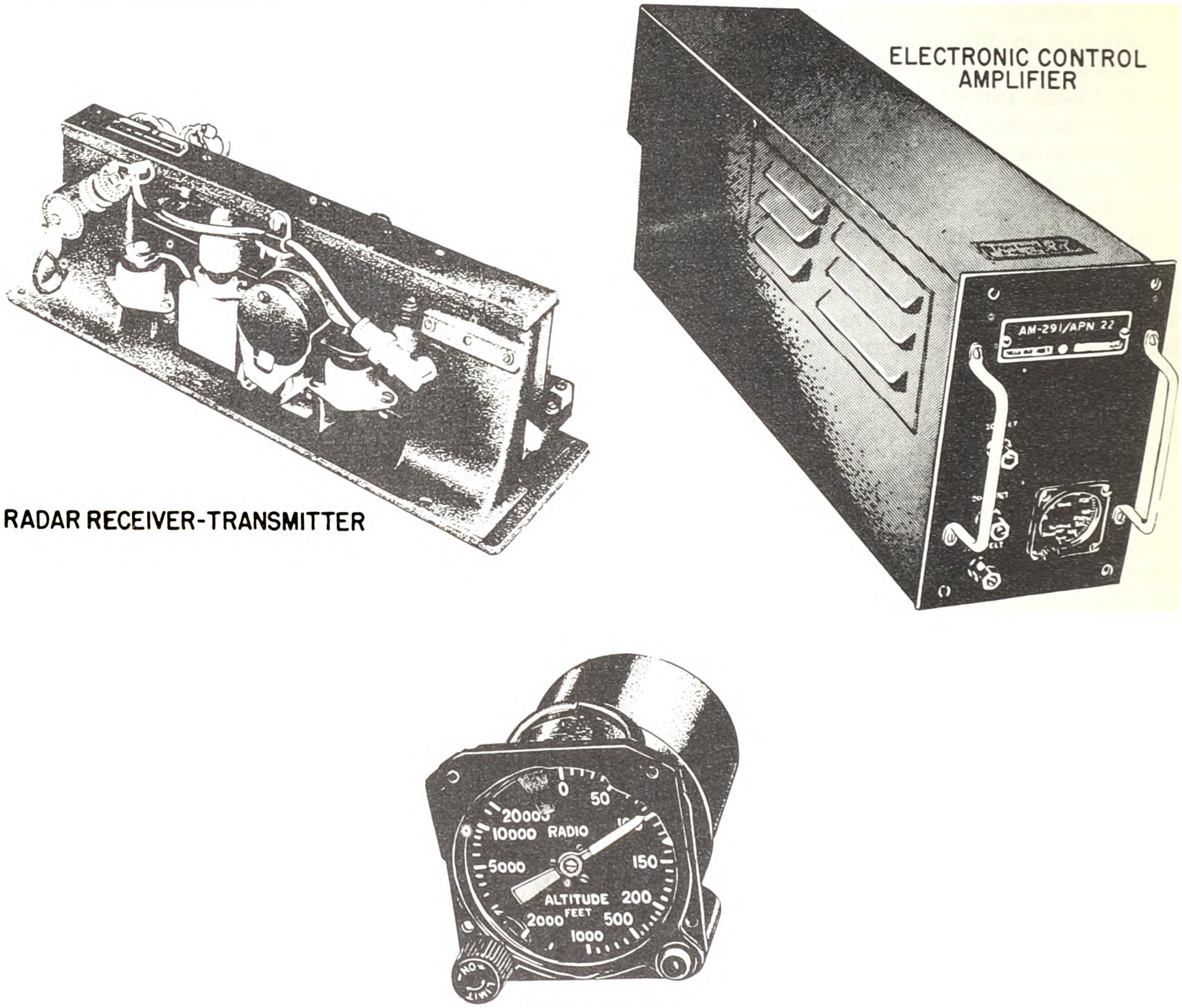
The APN-22 radar altimeter radiates a microwave signal which varies regularly in frequency in accordance with a 120-cycle triangular modulating voltage. The signal is directed toward the ground where a portion of it is reflected back to the receiving antenna. The echo wave is compared in the receiver with the instantaneous output frequency of the transmitter. An interval of time elapses between the moment the signal is transmitted and its arrival by reflection at the receiver. This time interval is directly proportional to the altitude of the aircraft since the wave travels with constant velocity. During this same interval of time the frequency of the transmitter changes. The echo wave and a portion of the transmitter output are applied to a balanced detector so that a heterodyne, or difference, frequency is produced. The value of the difference frequency in cycles is proportional to the time interval during which the wave travels to the ground and returns, and hence it is proportional to the altitude of the aircraft. (See fig. 12-24.)

The value in cycles of the heterodyne difference frequency depends on three factors, the relation being as follows:

$$f_d = \frac{f_m B h}{246}$$

in which f_d is the difference frequency in cycles, f_m is the sweep frequency of the modulator, B is the sweep width (the peak-to-peak frequency change of the transmitter in one cycle of modulation), and h is the altitude in feet or one-half the distance the radio wave travels. The difference frequency can be used as a measure of altitude as long as the sweep frequency (f_m) and sweep width (B) are held constant.

In the APN-22 system, the transmitter output is frequency-modulated by triangular waves at a frequency of 120 cycles per second. The sweep width is held constant at altitudes from 0 to 200 feet, and the difference frequency is used as a measure of altitude. Above 200 feet, the sweep width (B in the equation) is varied so that the difference frequency remains constant and the value of the sweep width is



RADAR RECEIVER-TRANSMITTER

ELECTRONIC CONTROL AMPLIFIER

HEIGHT INDICATOR

Figure 12-23.—Radar Set AN/APN-22.

used as the measure of altitude. A servo system is employed to measure the difference frequency and to control the sweep width. It also positions the point of the indicator for the proper altitude.

The APN-22 operates in the band from 4,200 to 4,400 megacycles. It provides reliable altitude information up to 10,000 feet when flying over land and up to 20,000 feet over water. The principal units of the installation are the receiver-transmitter, the electronic control amplifier, and the height indicator.

The receiver-transmitter is mounted on the underside of either a wing or the horizontal stabilizer or beneath the fuselage of the aircraft. The unit contains two horn antennas, the transmitter magnetron oscillator, a modulation transformer, and the two crystals used in the balanced detector. The receiver-transmitter radiates the microwave carrier, receives the reflected signal, and produces the heterodyne difference frequency. The transmitter section contains the magnetron which produces the microwave energy and a waveguide RF system used to feed the transmitting antenna.

The transmitter frequency deviation is about 60 megacycles at altitudes from 0 to 200 feet. From 200 to 20,000 feet, the frequency deviation depends on altitude and is reduced from 60 to 0.6 mc. over this altitude range.

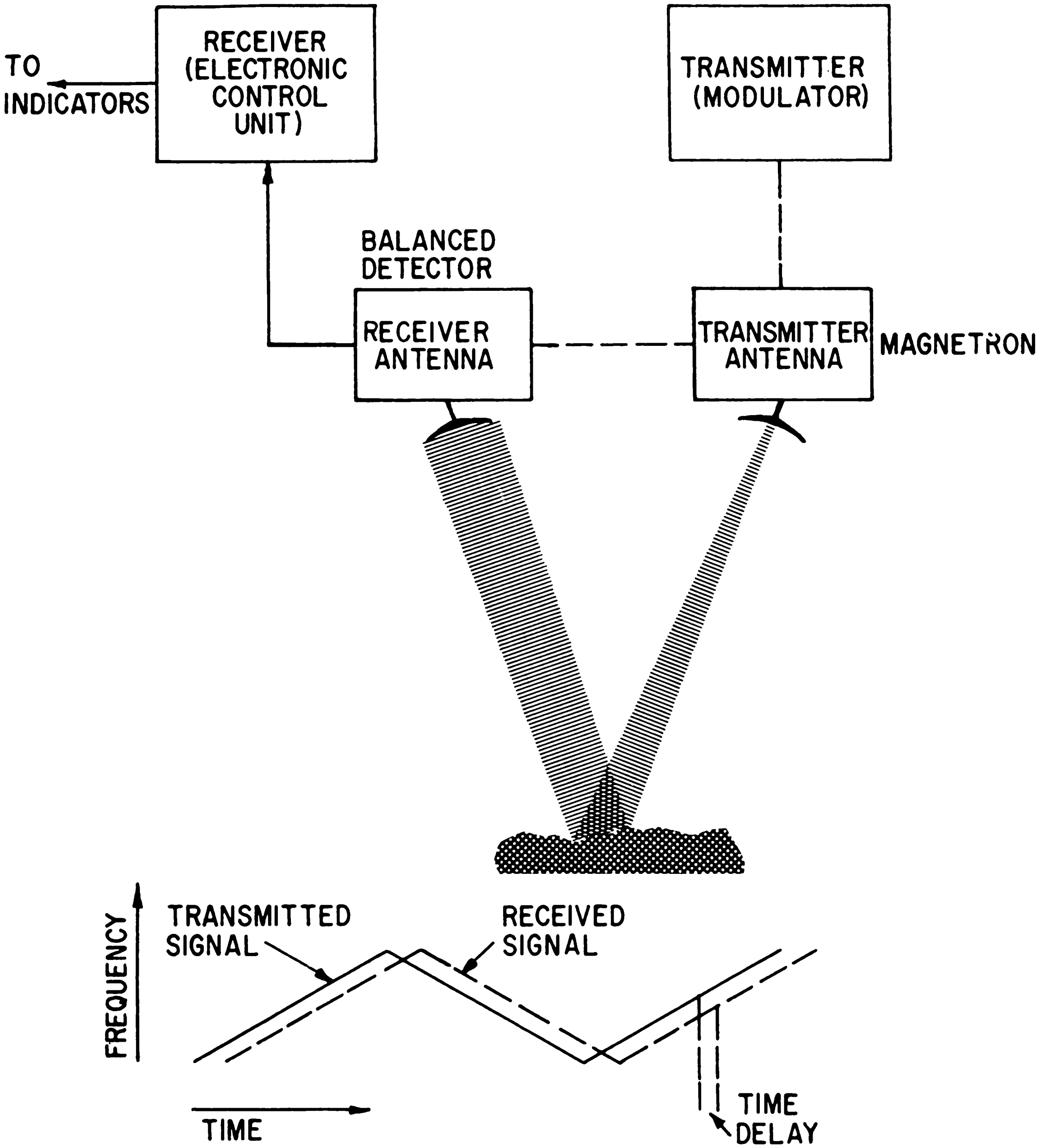


Figure 12-24.–Block and graph depicting time delay.

The average output power of the magnetron is about 1 watt. The energy is coupled to the transmitter waveguide by a short length of coaxial cable and is radiated from the transmitting horn antenna which is attached to the waveguide. A small portion of the magnetron output is also coupled to the balanced detector where it is mixed with the echo signals.

The balanced detector is a short length of waveguide containing two carefully matched crystal diodes. The diodes are attached to a special resonant circuit and to a horn radiator which is identical with the transmitting horn and which functions as the receiving antenna. The balanced detector mixes the two microwave signals and produces the difference frequency which is in the audio range. The output is applied to audio amplifier circuits in the electronic control unit.

All the required electronic equipment which is not located in the receiver-transmitter is contained in the electronic control amplifier assembly. This unit provides the plate and filament power for the various electron tubes of the system and in addition, serves the following purposes:

1. Generates the FM sweep voltage for modulating the magnetron.
2. Amplifies the heterodyne difference signal and converts it to a d-c voltage that is proportional to the detected frequency.
3. Employs the d-c voltage to drive a servo system which measures the beat frequency at altitudes up to 200 feet. Above 200 feet, the control unit varies the amplitude of the FM sweep voltage to determine the altitude.
4. Provides a synchro output voltage used to drive the indicator so as to give the altitude value.
5. Determines the reliability of the received signal and produces a warning indication if the received signal is of insufficient amplitude for correct operation.

The height indicator of the APN-22 displays the altitude information by means of a synchro-driven pointer and a scale calibrated in feet. The pointer repeats the position of the servo in the electronic control unit, giving a reading in feet of altitude as long as the signal received by reflection is adequate for reliable operation. In unreliable operation, the synchro which positions the pointer is disconnected from the control unit and a positioning voltage is applied, causing the pointer to assume an off-scale position.

The indicator unit also contains a limit altitude system in which a red light is caused to glow when the altimeter reveals that the plane is flying at a selected altitude or below this altitude. A potentiometer is included which transmits the limit altitude setting to the automatic pilot.

The only operating control of the APN-22 equipment is the on-limit knob with which the limit altitude is set and with which the equipment is turned off or on.

The two basic types of radar altimeters differ somewhat in accuracy. The pulse type altimeter has a fixed error of approximately 50 feet which is independent of altitude. The error inherent in the FM, CW altimeter is based on a percentage of the altitude indication (plus or minus 2 feet from 0 to 40 feet; and plus or minus 5 percent of the correct terrain clearance from 40 to 20,000 feet for the APN-22 radar altimeter).

Doppler Radar

The Doppler effect, or frequency change of a signal, will be explained in terms of an approaching and receding audio sound emitter. As shown in figure 12-25, the sound emitter is on a moving ambulance and the receiver is the ear of a stationary listener.

To the listener, an approaching sound will be higher pitched than a stationary or receding sound. As the siren approaches the listener, the sound waves (1,000 c.p.s.) strike the listener's ear. (See fig. 12-25(A).)

Notice the spacing between the waves from the stationary emitter *a*, as illustrated in figure 12-25 (B). If the emitter and listener were standing still, then 1,000 waves of sound energy would reach the listener in one second.

In *b* of figure 12-25 (B), the emitter is moving toward the listener (closing). The emitter moves a little closer to the listener between successive waves of energy, so each wave reaches the listener sooner than when the emitter was stationary. This means that the listener hears more than 1,000 waves of energy in one second, and consequently the sound is higher in pitch.

The reverse is true in *c* of figure 12-25 (B). The emitter is moving away (opening), so the

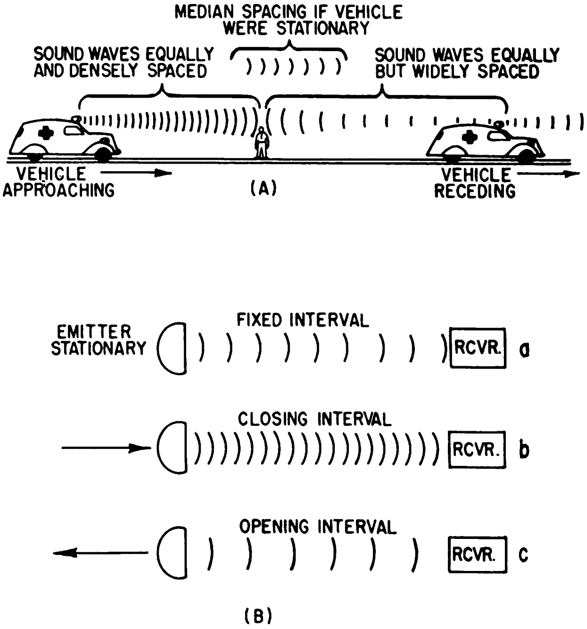


Figure 12-25.—Approaching and receding sound waves.

interval between successive waves is greater. Since the listener hears less than 1,000 waves in one second, the frequency is lowered and the pitch is lowered likewise.

APPLICATION OF DOPPLER TO RADAR

Doppler radar employs the frequency change phenomenon just described, except in the RF frequency range. (See fig. 12-26.)

The stationary radar emits CW energy at one frequency, and these waves of energy strike the target and are reflected. Energy waves returning from the target (aircraft) are spaced closer together than the waves striking the target. This is true because the target moves a little closer to the radar between successive waves, and reflects the waves sooner than if it were stationary. The closer-spaced waves mean that the frequency has increased slightly.

If the target moves toward the radar (closes) faster, the waves of energy will be even closer together, causing a greater frequency change. The faster the closing speed, the higher will be the frequency of the returning waves.

The receiver of the Doppler radar system has two signal inputs—one from the transmitter, and one from the receiver antenna. The input signal from the transmitter is at all times the same frequency as the signal being radiated; while the receiver antenna signal frequency will vary with the speed of the target. The two frequencies are compared in the receiver, and the difference frequency is a direct indication of the closing or opening speed of the target.

This receiver is designed to operate only when a difference frequency exists, and to ignore all returning signals of the same frequency as the transmitter. It follows that only a moving target will be detected, and reflected signals from stationary targets will be ignored.

NOTE: Do not confuse Doppler effect with the principle of the altimeter previously discussed in this chapter. The altimeter measures the time difference between signals, while the Doppler radar measures the frequency shift.

In the discussion just given, Doppler radar has been described with a closing target.

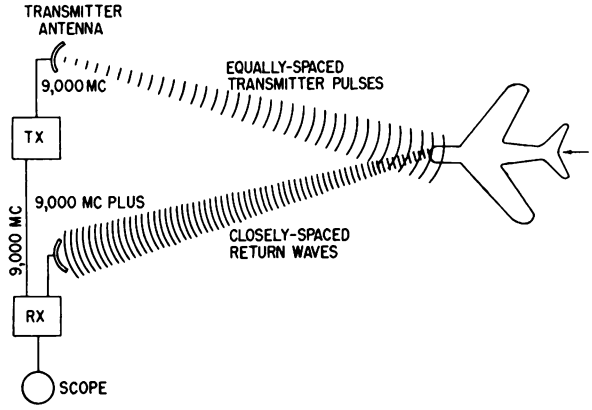

TRANSMITTER ANTENNA
9,000 MC
EQUALLY-SPACED TRANSMITTER PULSES
TX
9,000 MC PLUS
9,000 MC
CLOSELY-SPACED RETURN WAVES
RX
SCOPE

Figure 12-26.—Principle of Doppler radar.

However, like the sound waves shown in figure 12-25, the reflected RF energy would decrease in frequency if the target were opening (moving away). The amount of frequency shift would then be a direct indication of the opening speed of the target.

The Doppler effect is present any time there is relative motion (opening or closing distance) between the radar and the target. Therefore, the radar could be moving toward a stationary target and the effect would be the same as if a target moved toward a stationary radar. This type of radar could be used to calibrate the speedometer of an automobile, for it is highly accurate.

Doppler radar is normally designed for short-range applications, and will usually be a special mode of operation of a search radar. Some applications of Doppler radar are gun aiming, GCA (Ground Controlled Approach), and navigation. Its greatest value is in the fact that it will detect a moving target regardless of background reflections.

For example, during the Berlin crisis when Operation Airlift was being conducted, it was necessary that the aircraft approach the runway over the city and drop below the level of the buildings before landing. Doppler radar was employed in the GCA units on the field because the moving aircraft could be detected from the cluttered background.

Special Radar Attachments

GROUND POSITION INDICATING EQUIPMENT

Ground position indicating equipment continuously indicates the ground position of a flying aircraft from an initial reference point. One of its functions is to show north-south and east-west distances from the reference point on direct reading dials. Its primary function is to furnish voltages which will "ground

bilize" a radar sweep. This is accom-
shed by causing the PPI sweep to remain
ed geographically.

Search radar produces a PPI display that
ıstantly changes as the aircraft moves
ross an area. Since the sweep starting
nt represents the position of the aircraft in
center of an area, it follows that the PPI
esentation will change as the aircraft travels.
so, any targets on the scope will move
ross the scope. If, however, a target is
ected and the radar sweep is ground sta-
ized, the sweep starting point will change
l the targets will remain fixed in place on
scope. The radar continues to "view" only
selected area in which the target lies.

Automatic ground stabilization is parti-
arly advantageous in some radar applica-
ns. It simplifies the problems of ASW
eration by reducing calculations required
fly a sonobuoy pattern; it enables the opera-
to easily establish a track of moving targets
ch as ships, surfaced submarines, and
nicles on land; and the ground stabilization
ture can be used as a homing device from
asonable distances.

NAVIGATIONAL COMPUTER AN/ASA-13

The ASA-13 is an airborne, dead-reckoning
mputer which continuously determines
ound position from an initial starting point.
All the information necessary for its operation is contained within the aircraft. Necessary data to operate the ASA-13 are—(1) magnetic heading of the aircraft, supplied by the magnetic compass; (2) airspeed, supplied by the pitot pressure; (3) local magnetic variation, which is manually inserted to change magnetic heading to true heading; and (4) wind speed and direction, which are also manually inserted.

Airspeed Channel

Refer to figure 12-28. In performing its operations, this computer considers true airspeed, true heading, and time. The resolvers used in the ASA-13 computer are circuits designed to break up a vectorial quantity into two components. The outputs are the sine and cosine values of the quantity. The airspeed channel receives information from the pitot pressure and resolves this information into true airspeed. The servomotor then positions the N-S and E-W potentiometers in the heading channel to a value that represents true airspeed.

Heading Channel

Magnetic heading obtained from the aircraft's compass system is corrected to true heading in the heading channel. Voltage proportional to the directional components (N-S and E-W) of true heading, derived from a

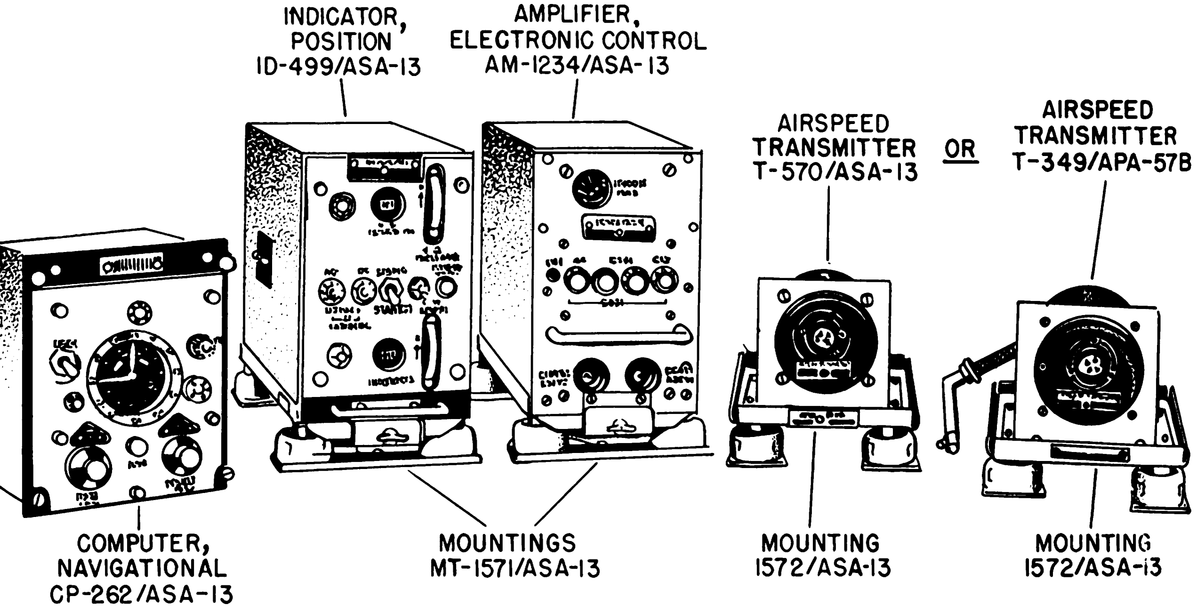

INDICATOR, POSITION ID-499/ASA-13
AMPLIFIER, ELECTRONIC CONTROL AM-1234/ASA-13
AIRSPEED TRANSMITTER T-570/ASA-13
OR
AIRSPEED TRANSMITTER T-349/APA-57B
COMPUTER, NAVIGATIONAL CP-262/ASA-13
MOUNTINGS MT-1571/ASA-13
MOUNTING 1572/ASA-13
MOUNTING 1572/ASA-13

Figure 12-27.—Computer group, navigational, AN/ASA-13.

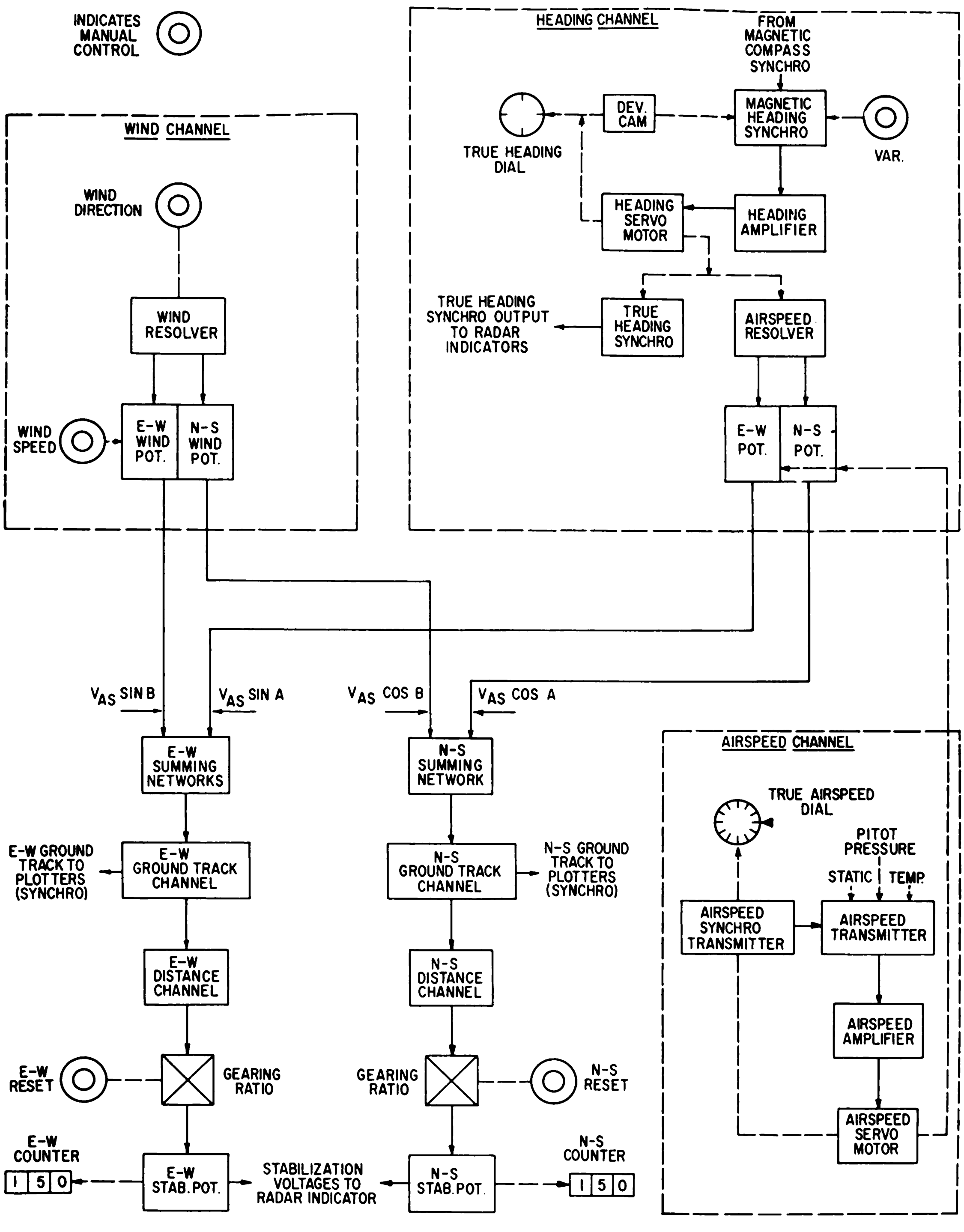


Figure 12-28.—Simplified block diagram of ASA-13.

sine-cosine resolver, are applied to the dual sections of the airspeed potentiometers. The shaft of this potentiometer is positioned by the output of the airspeed channel. As a result, the output voltage of one section is proportional to the N-S component of airspeed, while the output voltage of the second section is proportional to the E-W components of airspeed.

Wind Channel

Up to this point the computer has determined and combined true airspeed and true heading, and has developed outputs that are the sine and cosine of the vector addition. In order to determine ground speed it is necessary to insert the direction and speed of the wind. Wind data may be obtained by any of several methods, including aerology and drift sights. These two factors (speed and direction) are inserted into the wind channel manually, and the resolver's outputs energize the N-S and E-W sections of the wind potentiometer.

Ground Speed

The two inputs to each summing network are the components necessary to determine ground speed. The inputs are derived from true heading, true airspeed, and wind data readings. The N-S summing network receives the cosine outputs from the heading and wind channels. The E-W summing network receives the sine outputs. In the N-S summing network the N-S components of airspeed and wind are combined, and the result is an output voltage equivalent to the N-S ground speed of the aircraft. Similarly, the E-W summing network has an output voltage equal to the E-W speed of the aircraft. The N-S and E-W channels are identical from this point on.

After ground speed has been determined, adding the factor of time is the only remaining factor in order to compute distance. This is done in the ground track channels, and both channels operate in exactly the same manner with their respective voltage inputs.

Ground Track Channel

The ground track channel converts the component of ground speed into distance by taking into account the length of time the aircraft travels at the ground speed. This is done by a motor-driven tachometer (or rate generator) which rotates at a speed proportional to the ground speed of the aircraft. This rotation is in a direction corresponding to the direction of travel. A ground track synchro, coupled to the motor-generator, provides output data at two miles per revolution.

Distance Channel

The distance channels convert the rotation of the ground track synchros into distance counter information. By using synchros and servomotors, the information is transferred through a gearing mechanism that causes the stabilization potentiometers to provide the proper voltages to the radar sweep. These voltages (from the N-S and E-W stabilization pots) will ground stabilize the sweep so that the radar continues to view the area selected. The distance channel also positions the dials of the Veeder-root counter to indicate the distances traveled.

Capabilities of Equipment

The ASA-13 is designed to operate up to 30,000 feet and at temperatures from -67° F. to +131° F. The computer will ground stabilize a sweep up to 300 miles. Beyond this range resetting is required, resulting in the PPI origin being moved to a new position.

Airspeed Ranges

The ASA-13 can use either of two airspeed transmitters. For slow airspeeds (10 to 150 knots) airspeed transmitter T-570 is used, and its output is equivalent to indicated airspeed. For high airspeeds (100 to 400 knots) the T-349 is used, and its output is equivalent to true airspeed. The low-speed transmitter will normally be found in slow-moving craft such as LTA (lighter than air) airships.

QUIZ

1. The purpose of the automatic frequency control circuit is to maintain a constant
   a. transmitter frequency
   b. local oscillator frequency
   c. IF frequency
   d. crystal frequency

2. The compensating gate circuit is used to insure
   a. a constant oscillator frequency
   b. that the indicator sweep always starts at the same point
   c. a constant IF frequency
   d. a constant transmitter frequency

3. A 3-cm radar operating on beacon will have a pulse width of approximately
   a. 0.5 microsecond
   b. 2.25 microseconds
   c. 4.5 microseconds
   d. 6.18 microseconds

4. RF energy transmitted by airborne search radar is
   a. pulse modulated
   b. unmodulated constant wave
   c. frequency modulated
   d. amplitude modulated

5. The time required for RF energy to travel 10 range miles is
   a. 61.8 microseconds
   b. 12.36 microseconds
   c. 618 microseconds
   d. 123.6 microseconds

6. The AN/APS-33 radar is used primarily for
   a. aircraft early warning
   b. fire control
   c. search and navigation
   d. identification

7. The focus control of the AN/APS-33 radar varies the
   a. negative voltage on the control grid of the indicator
   b. positive voltage on the indicator cathode
   c. magnetic field of a permanent magnet around the neck of the tube
   d. positive voltage on the indicator accelerating anode

8. A radar altimeter such as the AN/APN-22 is
   a. pulse modulated
   b. unmodulated constant wave
   c. amplitude modulated
   d. frequency modulated

9. When a PPI scope is azimuth stabilized, the top of the scope indicates
   a. magnetic north
   b. true north
   c. aircraft heading
   d. astral north

10. The fixed delay circuit in the AN/APS-33 radar delays the firing of the transmitter to
    a. give better target discrimination
    b. eliminate ground return
    c. fire the transmitter on a linear portion of the sweep
    d. extend the range of the indicator

11. A radar system utilized for aircraft early warning differs from a basic search radar in providing for
    a. identification friend-or-foe
    b. radar relay link
    c. low altitude bombing
    d. fire control operation

12. The frequency deviation of the AN/APN-22 transmitter from 0 to 200 feet is
    a. 0.6 megacycle
    b. 6.0 megacycles
    c. 60.0 megacycles
    d. 600.0 megacycles

13. The radar synchronizer determines
    a. pulse repetition frequency
    b. pulse width
    c. power output
    d. carrier frequency

14. Effects of enemy jamming are minimized by the
    a. stretching circuit
    b. discriminator circuit
    c. delay circuit
    d. anticlutter circuit

15. A radar utilized as an all-weather fighter radar differs from a basic search radar by having a
    a. wider pulse width
    b. narrower pulse width
    c. faster pulse repetition frequency
    d. slower pulse repetition frequency

16. The percentage of error of the AN/APN-22 altimeter above 40 feet is
    a. 0.5 percent
    b. 0.2 percent
    c. 5.0 percent
    d. 2.0 percent

17. Most airborne radar operates in the
    a. MF band
    b. VHF band
    c. UHF band
    d. SHF band

18. In the radar duplexer
    a. the TR tube fires on transmit, the ATR tube fires on receive
    b. the ATR tube fires on transmit, the TR tube fires on receive
    c. both tubes fire on receive
    d. both tubes fire on transmit

19. A typical indicator pattern used for gun aim presentation is
    a. A scope
    b. B scope
    c. G scope
    d. PPI scope

20. The Doppler theory states that radio energy reflected from a moving target that is closing
    a. increases in amplitude
    b. increases in frequency
    c. decreases in amplitude
    d. decreases in frequency

21. To intensity modulate a radar indicator with a positive video signal, the signal is applied to the
    a. vertical deflection plates
    b. horizontal deflection plates
    c. control grid
    d. cathode

22. On beacon operation the frequency that is changed in the AN/APS-33 is the
    a. local oscillator
    b. radar transmitter
    c. IF amplifier
    d. video amplifier

23. The unit of an IFF system which acts as the challenger is the
    a. transpondor
    b. interrogator
    c. responder
    d. discriminator

24. When an airborne radar system is ground stabilized,
    a. all targets remain stationary on the indicator
    b. moving targets only remain stationary on the indicator
    c. stationary targets do not move on the indicator
    d. all targets move on the indicator

25. The output of the AN/ASA-13 heading channel is
    a. magnetic heading
    b. relative heading
    c. true heading
    d. astral heading

CHAPTER 13

ELECTRONIC COUNTERMEASURES

It is the purpose of this chapter to introduce the general principles involved in the operation of electronic countermeasures devices. In the discussion which follows, certain specific examples of countermeasures equipments are described to illustrate these principles. Because of security reasons the choice of equipments for this purpose is limited. The descriptions of the units included here are not intended to provide detailed information concerning maintenance and operation, but are given solely to present the broad basic facts which are common to many examples of countermeasures equipments, both old and new.

It is a basic rule of warfare that for each weapon used by the enemy, a counterweapon must be developed. This rule is clearly expressed in modern war by the development and use of electronic countermeasures (ECM). The counterweapon in this case is used against enemy electronic equipment—against radar, communication transmitters and receivers, navigation aids, and electronically controlled weapons (such as guided missiles and proximity fuses). The objective of ECM is to make the enemy's use of these electronic devices ineffective and to obstruct his profitable employment of the electromagnetic spectrum.

Electronic countermeasures consists of two general types of actions: passive and active. Passive ECM are operations which cannot be directly detected by the enemy, for example, reconnaissance or search operations, in which enemy transmitters are detected and located and as many as possible of the signal characteristics are determined. Passive countermeasures also include evasive tactics taken to avoid detection, and methods of controlling the radiations from friendly equipments to prevent the enemy from using the signals for homing, direction-finding, or for any other purpose.

Active ECM are actions which can be detected by the enemy and which prevent him from making effective use of his equipment. In the active phase, jamming transmitters are used to produce interference with radar and communications reception so that enemy receivers are subjected to obscuring and confusing radiations. This is called electronic jamming. Another phase of active radar countermeasures, called nonelectronic jamming, is often accomplished by the use of strips of metallic foil released from aircraft (and sometimes fired in projectiles). The falling strips intercept radar waves and reradiate them, causing numerous false targets to appear on the radarscope so that the enemy operator is unable to detect desirable targets and fire control radar is unable to see attacking planes.

Before active countermeasures can be undertaken, an extensive search, or intercept, campaign must be made to learn what types of electronic equipment are in active enemy use and the purposes for which they are employed. To gain this information, intercept flights are made in aircraft which carry special ECM equipment. With the equipment, the ECM operator tunes in signals from enemy units and measures their characteristics. He records the results in a log or acquires tape or film records which are later submitted to tactical officers for analysis and evaluation. The information gained is then used in planning active countermeasures, such as jamming, for directing control of radiation from friendly units, and for devising means for evading detection by the enemy equipments reported.

ECM receiving equipment may be used to detect, locate, and identify enemy ships, aircraft, or shore installations. This use of ECM equipment alone makes the equipment very useful. For example, in antisubmarine warfare a submarine can detect aircraft with its radar. The aircraft using ECM receiving equipment can stay out of range of the submarine's radar and still receive the submarine's radar signal because the radar signal travels much farther than the maximum detection range of that radar's equipment.

The principal kinds of ECM equipment used in collecting these data are:

1. SEARCH RECEIVERS, which are designed for intercepting signals occurring throughout wide ranges of frequency. Two

general types are used—those with narrow bandpass characteristics and those with wide bandpass. Receivers are usually equipped with several plug-in tuning units, each of which can be either manually tuned or automatically swept over a selected frequency sector by motor-driven tuning circuits. Some types of broadband receivers are untuned so that signals are received simultaneously over a wide frequency range. In others, rapid automatic tuning is used.

2. ANTENNAS. ECM antennas are broadband devices which respond to a very wide range of frequencies without excessive tuning adjustment. In many of the units, the assembly includes built-in impedance-matching sections.

3. PANORAMIC ADAPTERS are used as attachments for the search receiver. The adapter supplies visual indications of all signals present in selected frequency ranges and reveals the types of modulation and frequency of the signals intercepted.

4. PULSE ANALYZERS. These units are used for measuring the characteristics of signal emissions, and in some cases give visual indications of such properties as pulse shape, pulse width, and pulse repetition rate.

5. DIRECTION FINDERS are used to determine the relative bearing of a given signal source and to assist in locating enemy transmitters. In many ECM direction finders, cathode-ray tubes are used as indicators which enable the operator to distinguish the types of signals received and to detect characteristics such as lobe switching in fire control radar units.

6. RECORDERS. Tape and film recorders are used to make records of the signals received by the associated search receiver as it is tuned rapidly through the spectrum. The recording, which is analyzed after the flight, gives information concerning the frequencies of the signals, the amplitude, and the time of reception.

7. CATHODE-RAY OSCILLOSCOPES AND AUDIO OSCILLATORS are sometimes used to measure the repetition frequencies of radar pulses when a pulse analyzer is not available. The pulse repetition frequency is determined from the patterns which result from application of the received signal to the vertical deflection plates of the scope while sweeping the beam horizontally with the output of the calibrated audio oscillator.

The information derived with these various types of search equipment consists of the characteristics of the enemy signals. These properties form the basis for estimating the capabilities and weaknesses of the electronic installations and for devising effective jamming techniques to be used against them.

Signal Characteristics

To prepare effective countermeasures against communication systems and navigation aids, information is needed concerning the frequencies of the emissions, the types of modulation used, the polarization of the transmitted waves, and the exact locations of the stations. For countermeasures against enemy radar, much more information is required. The principal signal characteristics of importance are the carrier frequency, the pulse repetition frequency, and the pulse width. In addition, other data are very desirable. These include the type of scan employed, the rate of scan, the beam width, and the polarization of the antenna.

CARRIER FREQUENCY

The carrier frequency is the starting point from which the other signal characteristics are determined. Knowledge of the frequency is necessary for determining the type of the radar and its probable function and for preparing effective jamming operation.

PULSE REPETITION FREQUENCY (PRF)

The second most distinguishing characteristic of the radar is its pulse repetition frequency (PRF), or the number of pulses emitted per second. The PRF value is a factor in determining the maximum range of the unit since it governs the time interval between the pulses. Long-range air search radars must necessarily use low PRF values, since the pulses need to be spaced at intervals sufficient to allow echo signals to return from the most distant object within the desired range. Higher values of PRF are used in surface-search radars designed for detecting objects at shorter ranges; while extremely high pulse rates are employed in such equipment as fire control radars which have very short range but extreme accuracy.

PULSE WIDTH

It is desirable to know the pulse width of radar signals since this value is the basis for estimating the minimum range of the unit. Pulse width is the interval of time during which the radar transmitter is energized; and as a result, determines the shortest range at which objects can be received. In general, the longer the pulse width, the greater is the minimum range of the radar. In other words, the longer the pulse width the longer it takes the radar receiver to recover. Therefore, the minimum range at which that radar set can detect a signal is then a greater distance.

TYPE AND RATE OF SCAN

The type of scan, the method by which the radar beam searches the target area, is a good indication of the nature and action of the radar. Types of scan include 360-degree, sector sweeps, lobe-switching, conical, and spiral scans. The simplest way of distinguishing the scan type is by listening to the intercepted signals. Signals from search radars usually cause a whine in the headphones, the tone being produced by the constant pulse rate. In 360-degree scan, the signal strength varies periodically as the beam sweeps over the search plane. As long as the signal variations continue, the radar is searching; but if the sound becomes loud and steady, the indication is that the set has probably detected the search plane and is concentrating its attention on it. Fire control radars often use lobe switching in which the beam locks first to one side and then to the other of the target. The shifting of the beam takes place rapidly and brackets the target while the radar compares the echoes from each beam position. Lobe switching is easily detected by visual indications of the signals on panoramic adapters, pulse analyzers, and direction finders. It also causes a characteristic chatter in the headphones as the beam position varies.

The rate of scan or number of scanning sweeps made per minute, is related to the probable maximum range of the radar. Slow scanning is characteristic of long-range search sets, while short-range radars and fire control systems employ much higher scan rates. The rate is usually measured in terms of the time required for one scan. The signals are observed on the screen of a panoramic adapter or the scope of a direction finder. The operator logs the time interval between successive indications of maximum signal strength.

BEAM WIDTH AND POLARIZATION

The measure of the beam width gives an indication of the azimuth accuracy of the enemy set. The width of the beam, which is expressed by the number of degrees between the half-power points, is generally computed from data provided by automatic recorders which give information concerning the amplitude of the signals.

The polarization of the radar antenna is considered in planning effective methods of jamming. This characteristic can be determined by use of direction finders of the type which makes a visual display of the reception. The direction finder is equipped with two antennas—one polarized horizontally and the other vertically. Either antenna can be used for reception, and the polarization of the incoming signals is learned by comparing the patterns resulting from each.

A rough determination of polarization can be made by alternate shifting from vertical to horizontal receiving antennas. The antenna which is of proper polarization for the signal being received will provide an audible (panoramic) response indicating greater signal strength. Circular polarization will give approximately a uniform response on either antenna.

Passive ECM Equipment

SEARCH RECEIVERS

The success or failure of an intercept mission depends largely on the proper functioning of the search receiver, the basic type of passive countermeasures equipment. By means of the receiver, the ECM operator detects the presence of radar and radio emissions, monitors enemy transmissions, learns the types of modulation used, and is given indications of relative signal strength.

When searching for enemy radar locations, the ECM receiver operates at a fundamental advantage with respect to the radar so that reconnaissance can be carried out without fear of detection by the enemy unit. Radar detects objects by reflection, or two-way transmission, in which the reduction of signal strength is proportional to the fourth power of the distance covered by the waves. The receiver, on the other hand, detects the radar by a one-way transmission in which signal reduction is proportional only to the square of the distance. As a result, the presence of the radar can be detected at a distance greater than the maximum range at which the radar can detect the search plane.

Search receivers are either untuned crystal detectors which accept all signals in a wide frequency range, or else they are superheterodyne circuits that can be tuned rapidly over various bands. In the latter type, the extremely wide frequency coverage required is provided by the use of several plug-in tuning units, each of which covers a part of the total tuning range of the receiver. Tuning units usually consist of a tuned antenna circuit, a local oscillator, and a mixer stage. The receiver produces three types of output—intermediate-frequency voltages for use in a panoramic adapter, video signals which are applied to a pulse analyzer, and an audio output for the headphones. As already stated, a panoramic adapter is a cathode-ray indicator that enables the operator to sweep a broad spectrum of frequencies during a short period of time. When a signal that the operator desires to inspect closely is detected by the adapter, it is fed to the pulse analyzer for closer study.

In figure 13-1, a block diagram of a typical ECM superheterodyne receiver is shown. The receiver (AN/APR-9) covers a wide tuning range by employing four plug-in tuning units.

Signals intercepted by the antenna are fed to a connection on the receiver through a switching assembly. This assembly enables the operator to select the proper antenna for the frequency range to be covered. From the antenna connection, the incoming signals are applied to one of the four plug-in tuning units.

The tuning unit contains an RF amplifier, a local oscillator, a crystal mixer, an IF amplifier, and a d-c motor which is mechanically coupled to a synchro generator. The synchro generator transfers frequency information to a cathode-ray indicator unit.

Since there are no manual controls in these tuning units, they are usually remotely mounted to provide better utilization of space in the aircraft. The d-c also automatically tunes the RF amplifier and the local oscillator through their frequency range. When the frequency is too high for use with conventional RF amplifier circuits, tunable cavities are incorporated

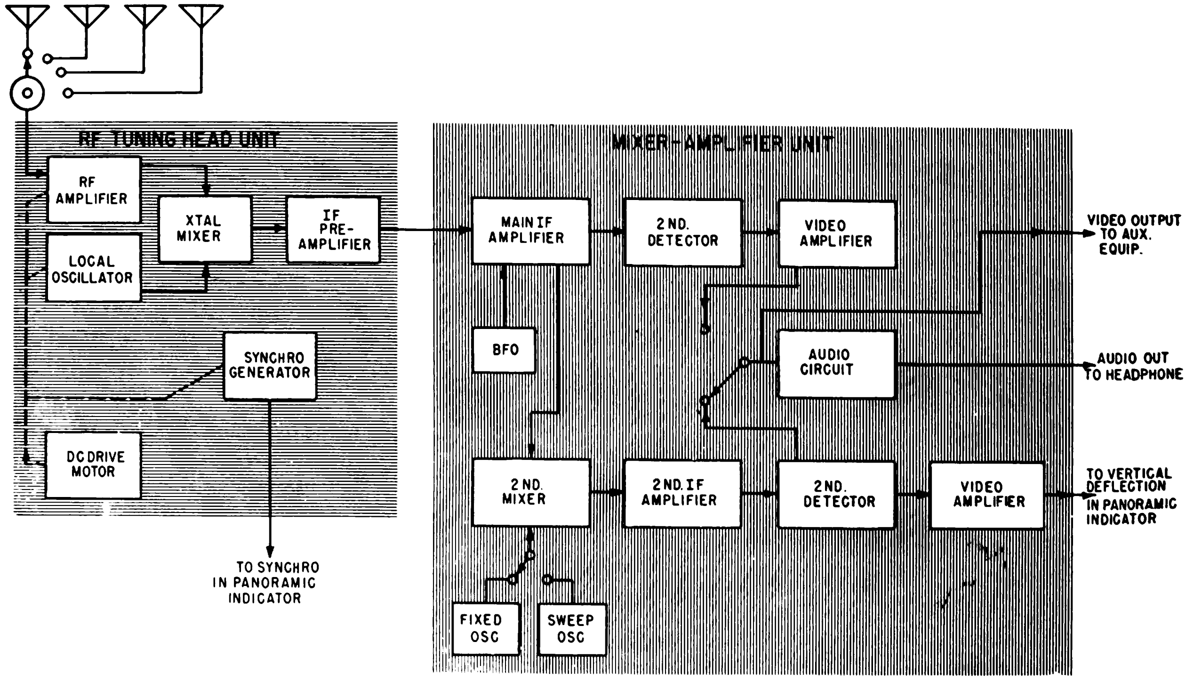


Figure 13-1.—Block diagram of ECM receiver.

instead. The popular name for these cavities is RF preselector.

Mixing of the input signal with the signal from the local oscillator, in a crystal mixer, produces an IF frequency. This IF signal is amplified through several stages of preamplification. The preamplifiers are stagger tuned; that is, each stage of preamplification is tuned to a slightly different frequency. This stagger tuning gives a very broad bandpass which is desirable for video work. The output is impedance matched to feed the signal into the next section, a mixer amplifier.

The mixer amplifier contains a main IF amplifier strip, a second IF amplifier strip, and the video and the audio circuits of the receiver. It also contains a sweep oscillator, a fixed oscillator, and a beat frequency oscillator (BFO). The BFO is a heterodyning oscillator used for detecting CW or MCW transmissions. The sweep oscillator sweeps through a spread of frequencies equal to the receiver bandpass. The sweep oscillator output is mixed with the signal from the main IF amplifier in the mixer stage to produce a new and lower IF frequency. This system of going from one IF to a lower IF is called double IF conversion and is done to produce a lower frequency. This lower frequency requires simpler circuitry throughout the remainder of the receiver. This second IF signal is fed through several stages of IF amplification, then to a detector stage. The detector stage produces a video pulse which is available for presentation on the indicator scope.

During broad-band operation the receiver may receive one or more signals simultaneously. In order to view one signal at a time the receiver is switched to narrow-band operation. Since it is mechanically difficult to stop the sweeping oscillator at the exact frequency needed for double IF conversion, a fixed oscillator is provided. The signal from the fixed oscillator is fed into the mixer during narrow-band operation.

From the main IF amplifier strip a signal can be detected, amplified, and then made available as a video input for some auxiliary equipment such as a pulse analyzer, a direction finder, or a remote indicator. Provisions are also incorporated so that any signal present will be amplified through an audio circuit to give an audio tone. This tone may be used to aid the operator in detecting signals. He can listen as well as look. This is desirable since it enables him to combat eye fatigue by not having to look at the scope continuously.

From the second IF of the mixer amplifier the video signal is fed to a CRT indicator for panoramic indications. The signal may also be fed to auxiliary equipment for further pulse analyzing or direction finding.

Search Antennas

Since enemy signals may appear over very wide ranges of frequency, the antennas used with ECM search receivers must necessarily be very broad in frequency response. To insure this, the antennas are made thick and stubby in structure so that the inductance value is low. As a result, the antenna stores very small amounts of energy and has a low Q with the broad frequency response which is characteristic of all low-Q circuits.

Two types of ECM antennas used with airborne search receivers are shown in figure 13-2.

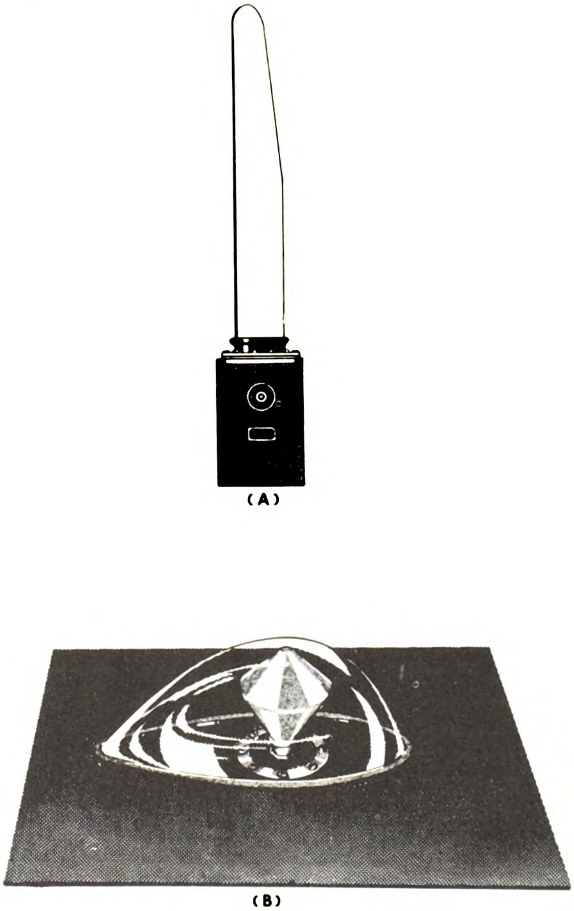


Figure 13-2.—(A) Stub antenna; (B) cone antenna.

e stub antenna, shown in (A), consists of oden mast about 22.5 inches in length is covered with a thick metal plating. lated area is connected to a receptacle ttachment to a 50-ohm coaxial cable. In cone antenna is shown. The reception n of the antenna shows uniform response directions perpendicular to the axis of one. The unit can be mounted either cally or horizontally for reception of waves her vertical or horizontal polarization. eception of both types of waves, the cone ounted at an angle of 45 degrees from the cal.

ny types of ECM antennas other than the llustrated are used in airborne installa- Usually the plane carries two of each employed with one mounted on the port- and the other on the starboard. Selection appropriate antenna is made by means of tch.

e Traps

arch receivers of the superheterodyne often produce spurious responses caused nage reception in which a station is re- d at two different positions of the tuning A second type of spurious response also ently occurs which is caused by harmonics e local oscillator. These beat with strong ls at frequencies other than that indicated e dial, and produce the intermediate fre- cy with the result that the stations are d in the output. There is another type of ous response, called pseudo image fre- cy, which is a strong signal beating with ndamental IF frequency. Since one of the ary functions of the receiver is to enable perator to determine the frequency of an cepted signal by means of the dial reading, device is needed to assist him in dis- ishing true signals from spurious re- ses. For this purpose, wave-trap stubs nable filters, are often used in conjunc- with these receivers. The wave-trap have a dial calibrated in frequency and e switched into or out of the antenna lead- Vhen the trap is in the circuit and tuned to requency of an incoming signal, the signal tered out and disappears from the output. neans of the calibration on the wave trap, perator can decide whether or not the sig- requency is actually that indicated by the eading at which he receives it. Generally, receivers used in the fleet today have image rejection ratios sufficient to permit direct dial readings.

Automatic Search Receivers

Modern ECM receivers use automatic tuning. The receiver's tuning section is driven by an electric motor which tunes the receiver across its entire tuning range. The tuning is continuous; that is, when the upper end of the tuning range is reached, the motor automatically reverses and the receiver is tuned down to the lower end of the band where again the motor reverses and the receiver is tuned to the upper end of its range.

Fully automatic search receivers are similar in operation to the automatic search receivers. However, there is one major difference. This difference is that fully automatic search receivers automatically stop tuning operations when a signal is detected. (NOTE: This is usually referred to as receiver lock-on). The signal may then be observed and its frequency noted by the operator. When the operator completes his observation, a button is pushed (on the control box) and the tuning drive again start through its tuning sequence from where it locked-on the last signal.

PANORAMIC ADAPTERS

Panoramic adapters are specialized superheterodyne receivers. They are used for monitoring a wide range of frequencies and provide visual displays of the signals intercepted by the search receiver. The signal indications appear on the screen of a cathode-ray tube. The station to which the search receiver is tuned appears as an inverted-V deflection at the center of the screen; and signals above and below this frequency show similar deflections to the right or left of center depending on their values. The amplitude of any deflection is determined by the strength of the corresponding signal, so that the panoramic screen is a graph of signal intensity versus frequency. (Signal intensity is indicated on the vertical axis, and relative frequency is represented on the horizontal.)

In search operations, the panoramic adapter is used principally as a tuning aid since the presence of many stations is indicated simultaneously. It can also be used to determine the types of modulation of intercepted signals and for observing the effects of one's own jamming emissions.

Interpretation of Patterns

Since a comparatively large number of signals may be observed simultaneously on the screen of the panoramic adapter, the instrument has great value in detecting enemy transmissions. Furthermore, the experienced operator can obtain additional information concerning the nature of the transmissions by inspection of the patterns. The oscillograms produced by several types of signals are shown in figure 13-3.

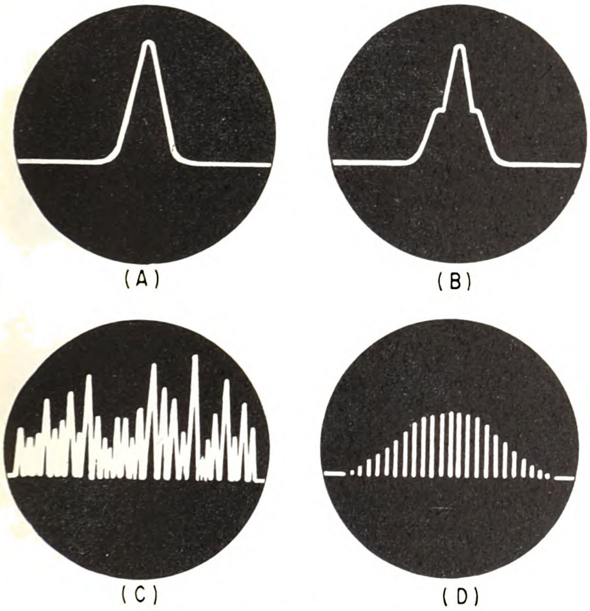


Figure 13-3.—Panoramic adapter patterns.

A constant carrier appears as a deflection with fixed height as shown in (A) of figure 13-3. Amplitude-modulated carriers appear as deflections which vary in height. If the modulating frequency is high, the sideband frequencies appear separately, causing pips on either side of the carrier deflection. Modulation with a single audio tone produces the pattern shown in (B) of the figure. A frequency-modulated carrier appears to wobble sideways. When the carrier is frequency modulated by voice or music, the appearance is a number of deflections which spread across a variable band as in (C) of the figure. Pulse modulation gives the pattern shown in (D) of the figure when the pulse repetition frequency is considerably greater than the rate of sweep of the indicator beam.

A CW signal appears and disappears with the keying of the transmitter. Two signals which are near enough in frequency to produce an audible beat note appear on the screen as a single carrier which varies in amplitude at the beat frequency. Noise voltages which vary regularly produce deflections which move across the screen in either direction—the motion being caused by the fact that the noise pulses are not synchronized with the panoramic sweep. Noise and interference, such as static bursts which are not periodic, produce irregular deflections and flashes along the length of the screen.

If image reception takes place in the associated receiver, the image signal has the same sort of appearance as the true signal. However, when the receiver tuning dial is rotated, the image pip moves in the opposite direction to that of the true signal deflection.

PULSE ANALYZERS

Pulse analyzers are used in ECM operations for measurement of the pulse repetition frequencies and pulse widths of radar signals detected by search receivers. The analyzer can also supply information concerning lobe switching, rotation rates, and beam widths of radar transmissions. In many pulse analyzers, the data are presented visually by means of cathode-ray tubes, although in some the pulse width and PRF values are indicated on meters. An example of the type using a cathode-ray tube as an indicator is shown in block diagram form in figure 13-4. The equipment shown, AN/APA-74, is a synchroscope. (A synchroscope differs from an oscilloscope in that an input signal must be used to trigger the sweep. In actual practice this signal will be caused by a target being received.)

This analyzer's cathode-ray tube is unique in that it contains five separate electron guns within one glass envelope. The horizontal beam of each electron gun sweeps at a different frequency. Therefore, the signal target that appears is shown on five different time bases. Various scales are engraved on the cursor so that desirable readings may be obtained. The two top scopes will show wide pulses so that pulse width may be observed. The three bottom scopes will indicate frequency and PRF.

The pulse, from a search receiver, that is fed into the pulse analyzer follows two paths. One is to a pulse shaper which produces pulses having the same width and repetition frequency as the received video signal as well as constant amplitude and rise time. The shaper output

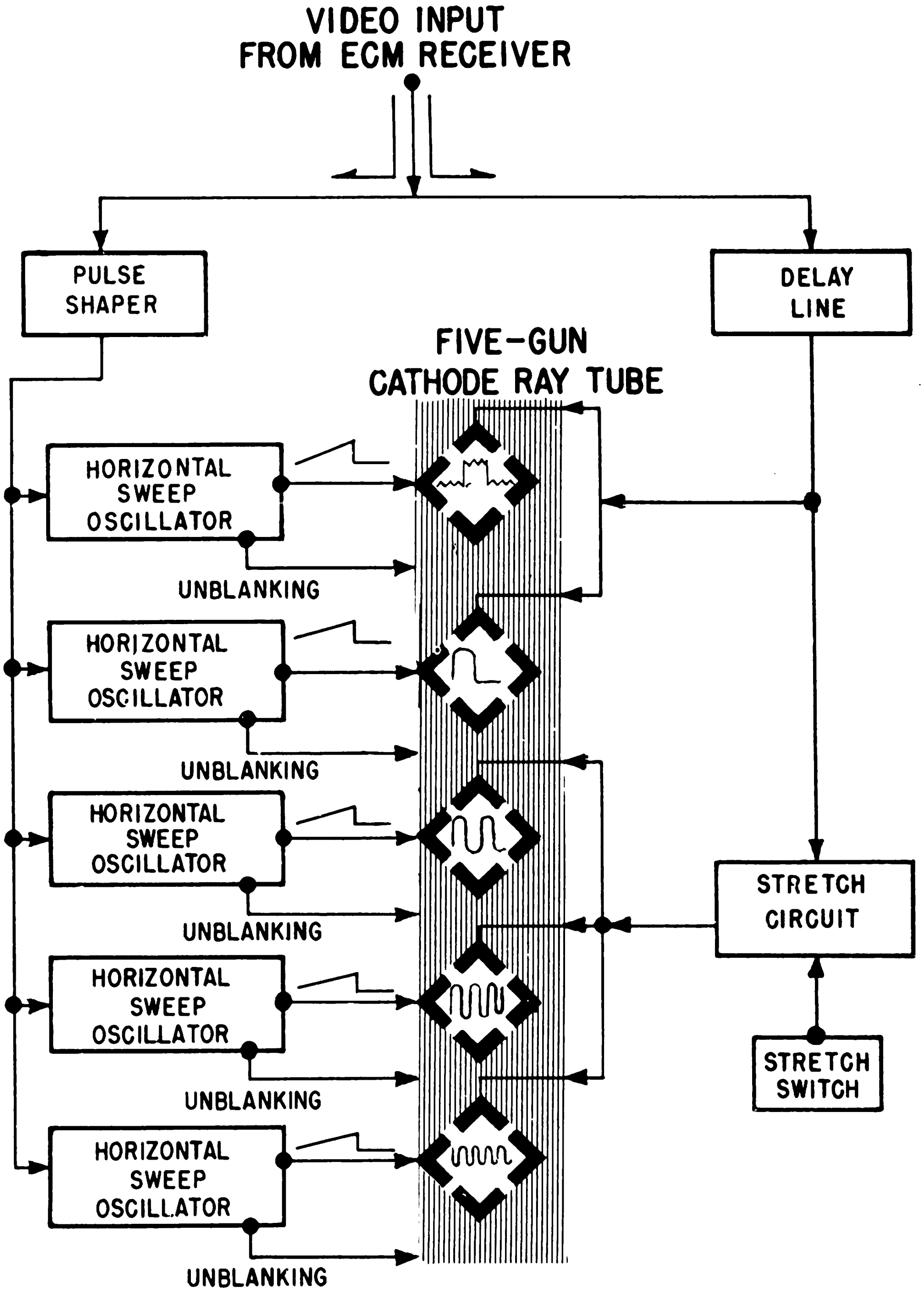

VIDEO INPUT
FROM ECM RECEIVER
PULSE SHAPER
DELAY LINE
FIVE-GUN CATHODE RAY TUBE
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
STRETCH CIRCUIT
STRETCH SWITCH

Figure 13-4.—Block diagram of pulse analyzer.

starts the horizontal sweeping action that unblanks each scope.

The other path is through a delay line to the five vertical plates of the CRT. This delayed signal is the deflecting voltage which produces a deflection of each time base so that signal characteristics are indicated. The delay is for a very short period of time. This insures that the leading edge of the pulse will be presented on the scope. In the last three electron guns the horizontal frequency is sometimes so long compared to the signal frequency that the signal does not appear on the CRT. In this case a stretching circuit can be switched in.

The stretching circuit broadens, or stretches, the signal enough so that it shows on the scope.

Figure 13-5 shows the indicator of the AN/APA-74. The screen is marked so that pulse width and PRF are read directly from the screen. For security reasons certain numbers and marks have been purposely blurred.

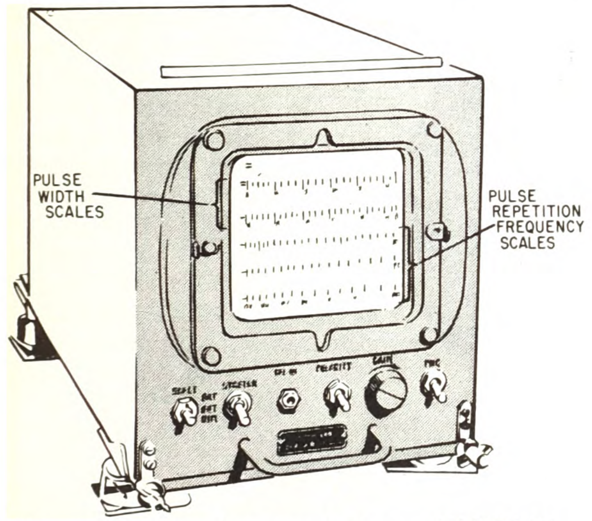


Figure 13-5.—Signal analyzer indicator, AN/APA-74.

When lobe switching is used by the enemy, the pulse width pattern will appear as shown in figure 13-6. Because of lobe switching the trace will not be steady but will appear to jump up and down. Although figure 13-6 shows a lobe switching pattern on only one line, in actual practice the pattern would appear on all five lines.

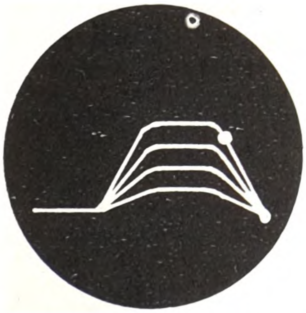


Figure 13-6.—Pulse width pattern obtained from lobe switching.

ECM DIRECTION FINDERS

One of the essential things to learn about any radar or radio station operated by the enemy is its exact location. In search intercept flights this information can be obtained by the use of airborne ECM direction finders which have been developed for this particular purpose. The enemy transmitter reveals its location as long as it is sending out radio waves; but the problem of analyzing the emissions is complicated by the fact that the enemy may choose either vertical or horizontal polarization. Consequently, the direction finder must be capable of receiving either type of transmission.

In ECM direction finders designed for higher frequencies, typical equipments employ continuously rotating antennas which are highly directional. Signals received are displayed on a cathode-ray indicator on which is presented a polar diagram of reception obtained throughout 360 degrees of rotation of the antenna. The pattern contains a major lobe which indicates the relative bearing of the station whose signals are displayed.

To locate a particular transmitter, the operator makes several readings of its relative bearing by means of the direction finder display. Each of these readings is called a "cut." With each cut, he records the time and the compass heading of the plane. This information is given to the navigator, who can determine, from the track of the flight, the exact location of the aircraft corresponding to each direction-finding cut. The track of the plane is then drawn on a chart and along it is marked the position at which each cut was made. Through each position a line is drawn, which makes an angle with the track equal to the recorded value of the relative bearing for that point. The intersection of the lines on the chart indicates the position of the enemy transmitter.

The direction finder display can also be used to learn the types of modulation of intercepted signals and to estimate pulse widths and repetition rates, and to determine the polarization of radar antennas.

Indicator Patterns

The cathode-ray screen of ECM direction finders employing visual displays shows the operator a polar graph on which the strength of received signals is plotted against relative bearing. To form the patterns, signals are received by the rotating antennas which are synchronized with the sweep of the cathode-ray beam of the indicator tube. Signals are received from a very small sector at any one time and are amplified and detected in the search receiver. Video pulses from the receiver are applied to the direction finder for further amplification and when applied to the indicator tube produce patterns similar to those shown in figure 13-7. With each video pulse the electron beam in the CRT is deflected outward from the center of the screen so that the length of the trace indicates the relative signal strength. The angular direction of each trace line represents the direction in which the antenna is pointing when the corresponding signal is received. The indicated bearing can be either relative or true, depending on the type of direction finder being used.

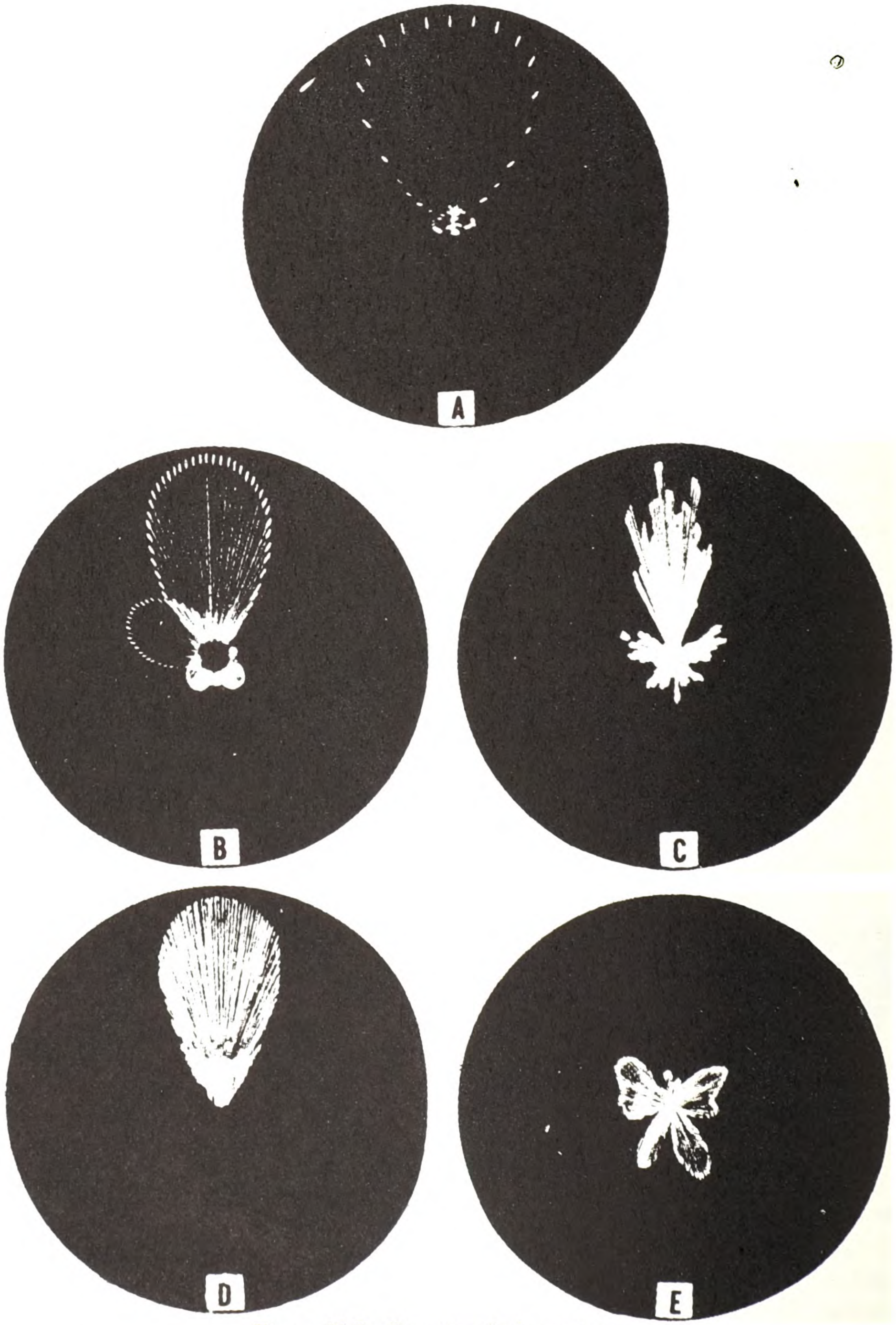


Figure 13-7.—Direction finder patterns.

To read the relative bearing of a station when its signal is displayed, the operator uses a movable mask on which is inscribed an arrow and which is fitted over the indicator screen. He rotates the mask until the arrow bisects the major lobe of the pattern and then reads the relative bearing on a graduated scale surrounding the face of the indicator tube. In an indicator that reads true bearing, the azimuth scale is automatically rotated around the outer rim of the CRT.

The pattern shown in (A) of figure 13-7 results from the signals of a search radar located dead ahead of the aircraft. The PRF is a comparatively low value as indicated by the wide spacing of the traces. Bright tips appear at the trace ends which are characteristic of pulse-modulated waves such as are emitted by almost all radar transmitters. In (B) of the figure the indicator pattern is that resulting from simultaneous reception of two radars on different bearings.

In (C) of figure 13-7, the pulses are grouped in sets of different length, indicating a lobe-switching radar, possibly a fire control system. The pattern varies with the location of the search plane relative to the direction of the radar lobes. When the pulse groups form a smooth pattern with all traces of equal length, the indication is that the plane is being bracketed by the switching lobes of the radar and that the guns controlled by it are probably trained on the observer.

A signal from a communications transmitter employing voice modulation is shown in (D) of the figure. Communication signals are easily identified by the fact that they do not produce bright tips on the trace lines and the pattern has a fuzzy appearance. The pattern shown in (E) does not display a marked major lobe and indicates that the polarization of the direction finder antenna is different from that of the polarization of the received waves.

In radar patterns, the lengths of the bright tips on the trace lines provide a means of estimating the pulse width. With the unit whose display patterns are illustrated in figure 13-7, the ratio of the bright length to the total trace length expressed in percentage is approximately equal to the pulse width in microseconds. For example, if the bright tip is about 5 percent of the trace length, the pulse width is approximately 5 microseconds. The pulse repetition rate of the radar can be estimated roughly by the amount of spacing between the trace lines; however, the spacing is governed to some extent by the rate of rotation of the receiving antennas as well as by the PRF of the signals.

An example of ECM direction-finding equipment which provides the type of display illustrated in figure 13-7 is the AN/APA-69. This direction finder, when used with suitable radio or radar receivers, provides visual indications on a CRT. This indication gives the true bearing of the received radio or radar signals. The directional indication is converted to true bearing by an azimuth scale which rotates around the outer rim of the CRT. Other information can be obtained from the CRT picture, such as approximate PRF, relative signal amplitude, modulation characteristics, and signal polarization.

The AN/APA-69 direction finder consists of five major units. (See fig. 13-8.) These are an antenna unit, an antenna drive assembly, an amplifier-power supply unit, an azimuth indicator, and a control box. The receiver used is one such as the AN/APR-9, which was previously discussed, and its video signal is supplied to the amplifier-power supply unit. This unit consists of a video amplifier and the power supply necessary to operate the direction finder.

The azimuth indicator consists of a three-inch CRT indicator. It has external adjustments for controlling the vertical and horizontal positioning, and the focus and intensity. The indicator unit also has a torque unit and a gear train. These rotate the moving scale for the azimuth reading.

The control box is located at the operator's position. It provides means for selecting the proper antenna, varying the speed at which this antenna is rotating, switching the polarization of the antenna, varying the gain of the video amplifier, and turning the primary power off and on.

The antenna drive assembly has a d-c motor and a gear train to drive the resolver and the antenna. The video signal from the intercept receiver is amplified and then passed through the resolver which is geared to the antenna drive shaft. This resolver voltage is then delivered to the plates of the CRT. It impresses on the tube a signal which is a radius vector rotating about the center of the CRT. The rate of rotation is the same speed as the antenna's rotation. Signal characteristics which create a distinctive pattern on the CRT are radar PRF, relative signal amplitude, modulation characteristics, and polarization. The best

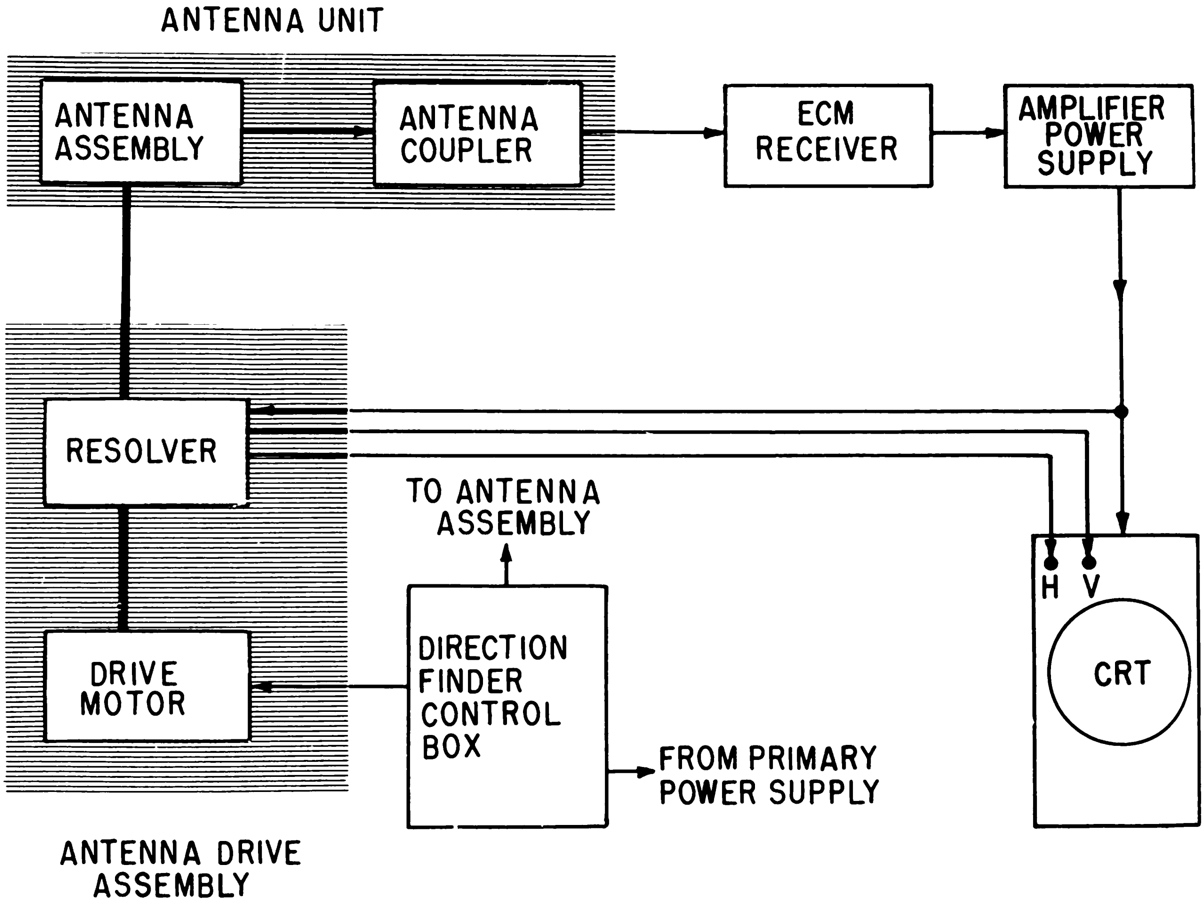


Figure 13-8.—Block diagram of APA-69 direction finder.

way to become familiar with and to gain skill in interpreting the great variety of patterns that may possibly appear on the CRT is by observing known scope patterns (characteristics). Refer to figure 13-7 for illustrations of representative scope patterns. A certain amount of deduction will inevitably be necessary because of the almost infinite number of possible pattern combinations.

The antenna assembly is an essential unit of an ECM installation. Ideally there would be two directional antennas for each frequency range, one polarized vertically and the other polarized horizontally. From the standpoint of space and weight this is impractical for aircraft installations. Aircraft ECM antennas are constructed so that they cover a broad band of frequencies and possess different polarization characteristics. Also, more than one antenna is mounted on the same antenna base.

Figure 13-9 shows a type of construction that is used in ECM direction finder antennas. Notice that there are three separate directional antennas. This practice makes possible the coverage of different frequency ranges. Also notice the different types of polarization used.

The three antennas are mounted on the same disk and may rotate through 360 degrees. Only one antenna is active at a time as selected by a polarization switch on a remote control panel. This polarization switch selects the frequency band desired and the type of polarization used with the selected antenna. The feed of the parabolic reflector antenna (A) is rotatable through a 90-degree angle to provide for reception of both vertically and horizontally polarized signals.

The combined function of all of the units that make up the AN/APA-69 direction finder is to produce a CRT pattern of the received radio or radar signal. This pattern is produced in such a manner as to indicate the direction from which the signal is being received and then to convert that direction indication into a true bearing by means of the rotating azimuth scale.

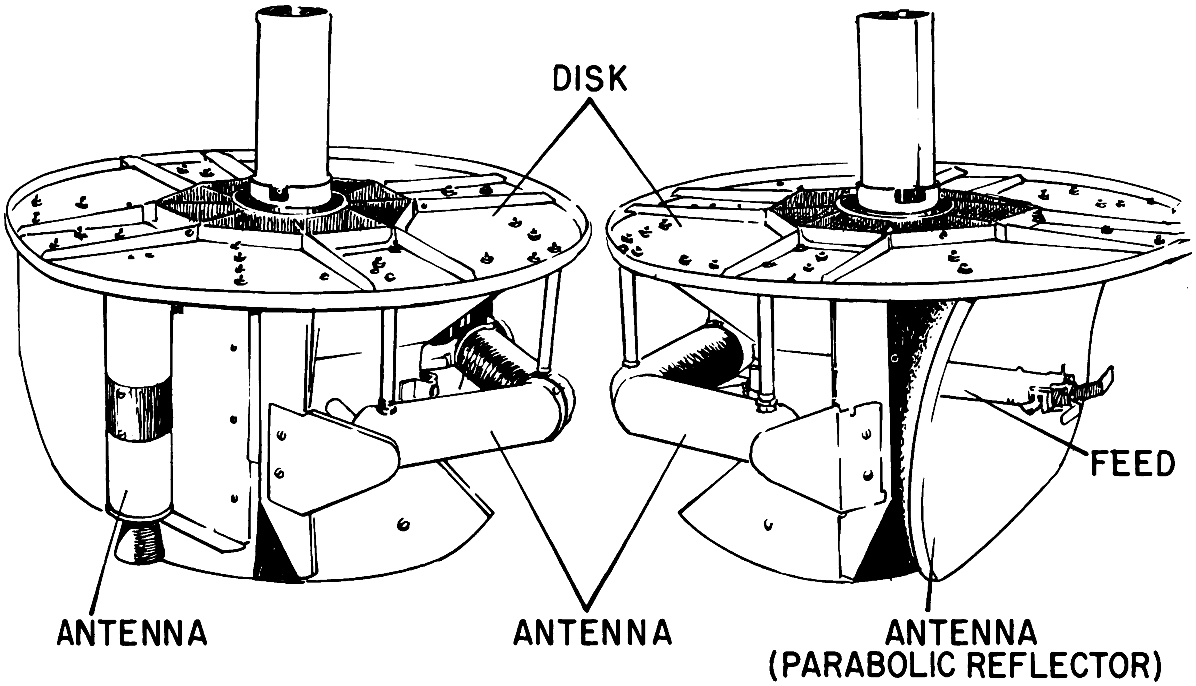


Figure 13-9.—Direction finder antenna.

Active ECM Equipment

Active electronic countermeasures are actions taken against the enemy's electronic devices, which he can detect, and which reduce his effective use of them. These actions consist of jamming, of deception, or a combination of both. The equipments used are of two general types: electronic and nonelectronic. The electronic type includes jamming transmitters and pulse-repeating units. The jamming transmitter is used to override and interferes with reception of communication, navigation, or radar signals. Pulse-repeating devices are used for deception and are similar to radar beacons. They receive radar signals and respond with pulses which give the enemy false information concerning bearing or range.

Nonelectronic devices are reflecting materials which act as false and confusing targets for enemy radar. They produce echoes by reradiating the radar waves so that signals are returned to the enemy radar receiver which resemble signals returned from aircraft. Nonelectronic equipments include short strips of metallic foil called window; longer metallic strips called rope; and corner reflectors, which simulate targets much larger than the device itself.

JAMMING TRANSMITTERS

Electronic jammers are tunable radio transmitters used for producing interference. The jammer radiates a carrier wave modulated with audio voltage suitable for drowning out reception or overloading enemy receivers. One of the most effective kinds of modulation for this purpose is random noise similar to the background disturbances heard in sensitive radio receivers when no station is being received. Noise makes a very desirable jamming signal since it distributes energy over a wide range of frequencies and cannot be filtered without loss of the desired signals. It is also difficult to recognize as manmade interference because of its similarity to atmospheric static impulses. A second type of jamming modulation is caused by sweeping the carrier over a wide range of frequencies at an audio rate. This produces a noise in the receiver much like that of an aircraft engine. Another type consists of a repetition of several audio tones, three to five in number, which give rise to a wailing sound when received.

When operated against radar receivers, the ECM jammer works at a distinct advantage since the echoes returned from most targets are very weak, and the jamming signal usually competes only with low-level radar signals. Hence, an output power in the order of tens of watts can effectively overcome radar pulses originally emitted at a peak power in the order of kilowatts. As a result, low-powered transmitters can jam enemy radar reception at far greater ranges than the maximum effective range of the radar. However, it is necessary that the jamming signal be radiated continuously, so that the output of the ECM transmitter is often as great as the average power of the radar it can successfully jam. Since jammers are operated continuously, adequate cooling must be provided. This is usually accomplished by fans, but may be accomplished by other means such as a water jacket around the transmitter to carry away the heat.

ECM transmitters are used in one of two ways, called spot jamming and barrage jamming. In the first of these, the operator tunes the jammer to the exact frequency of the receiver to be victimized by first tuning in the enemy signal with a search receiver. He then adjusts the output of the transmitter until the two signals coincide in frequency. Tuning for spot jamming is usually done in flight. Barrage jamming is accomplished by using a number of transmitters as in a formation of planes with each plane carrying at least one jamming transmitter. The units are pretuned to frequencies which differ by about 3 megacycles, a typical value of the bandwidth of an ECM transmitter. When all units are turned on, a wide range of frequencies is completely covered.

An example of an airborne jamming transmitter is the AN/ALT-2, which is shown in block diagram form in figure 13-10.

The AN/ALT-2 countermeasures transmitting set is an airborne noise modulated transmitting system. It is designed to jam enemy radar signals of any polarization over a wide frequency range. This transmitting set is suitable (1) for use as a spot or sweep jammer, (2) for manual use with currently used ECM receivers, and (3) for use as part of the AN/ALQ-23 Electronics Countermeasures Set. This set is a light-weight airborne noise modulated jamming system which may be controlled either automatically or manually. The jamming transmitter is similar to the ECM receiver in that it covers a wide frequency range by using plug-in tuning heads. The noise source is generated by a special type tube. This noise is amplified through several stages of video amplification. This broad band of frequencies is fed to a pair of high powered modulator tubes.

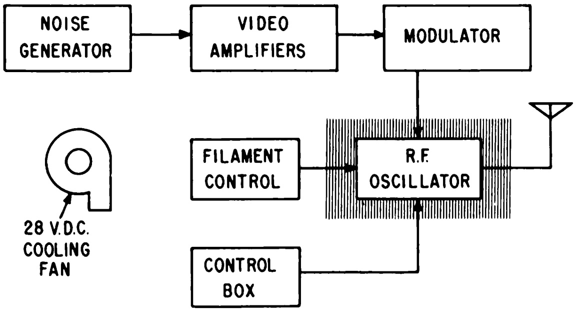


Figure 13-10.—ECM jamming transmitter.

The RF oscillator stage is the stage that is replaced when different tuning heads are used. Each stage contains a mechanically tunable magnetron oscillator which is modulated by the generated noise signal. The cathode filament of the magnetron receives enough power from back bombardment of electrons, when plate voltage is supplied, to materially shorten the life of the magnetron. Therefore, a-c power applied through the filament transformer must be varied to keep that filament temperature constant. This is the function of the filament control unit.

The operator selects the mode of operation of the transmitter with the control box. Transmitter frequency may be changed manually by the operator's turning a knob, or it will change automatically if set for automatic operation. A switch is incorporated on the control box which allows the operator to switch out the noise generator. When this is done the transmitter produces CW transmission, otherwise the output is modulated. The purpose of this switching arrangement is to produce another confusion factor for the enemy.

AUTOMATIC JAMMING EQUIPMENT

Automatic jamming equipment consists of an automatic search receiver and an automatically tuned jamming transmitter.

The sequence of operation is as follows: The receiver searches a desired frequency range; and when a signal is detected, the receiver locks-on this signal. As the receiver locks-on the transmitter is automatically tuned to the same frequency. When the transmitter tuning cycle is completed the transmitter is then automatically keyed to begin jamming operation. Different types of jamming (pulse, noise, etc.) may be produced by the transmitter. The particular type of jamming to be used by the transmitter is preselected by the ECM operator.

It should also be noted that this system may be switched to manual operation. This enables the ECM operator to manually perform the sequence of steps in the operation of the system.

ANTIJAMMING CIRCUITS

An ECM development relating to active jamming is the antijamming circuit often installed in receivers, particularly those in radars. The antijamming device is designed to decrease the effectiveness of enemy jamming and hence is called a "counter-countermeasure." These circuits have two uses: They prevent interfering signals from overloading the receiver, and tend to separate the desired signals from the jamming signals. Typical antijamming circuits are simple inductance-resistance filters of the high-pass type. The effect of the circuit, which is usually associated with the video detector section in the receiver, is to pass the high frequencies present in the signal and suppress low-frequency components. As a result, the leading edges of pulses are accepted by the circuits following the filter and large blocks of jamming voltage are excluded from the video amplifier circuits.

NONELECTRONIC JAMMING

Window and rope are code names for strips of aluminum foil used for nonelectronic jamming. The strips act as reflectors; and when released from aircraft, they return echoes to enemy radar receivers. Window (also called chaff) is tuned material. The strips of foil are cut to one-half wavelength of the radar signal to be reflected, and each strip acts as a resonant dipole antenna which intercepts and reradiates energy. The dipoles are packaged in cardboard folders which are either dropped manually or released by automatic window dispensing devices. Each package contains foil cut for a certain frequency so that a folder may contain from 50 to over 200,000 dipoles, depending on the wavelength of the system for which it is prepared. Typical bundles contain several thousand strips, and weigh less than two ounces. When the package is released, it opens so that the dipoles scatter into the air and begin falling at the rate of about 400 feet per minute.

Skilled radar operators can distinguish between aircraft pips and a single window echo; and for this reason, window is seldom dropped in isolated packages. Usually, a lead plane lays down a path consisting of many packages spaced at intervals of 1,000 feet or less. The planes which follow in the formation fly through the resulting clouds of reflectors, and enemy operators find it difficult to separate the single pip of an airplane from the mass window echoes. Thus, the following planes are protected from radar controlled antiaircraft fire and concealed from air search radars. On the radarscope, the dispensing plane appears as a pip which divides into two parts. The pulse representing the aircraft moves across the screen while additional echoes appear behind it and remain stationary. As the dipoles disperse in the air, the stationary pip grows into a shapeless mass in which the following aircraft are practically invisible. Aircraft must be inside the cloud of reflectors to be hidden; and those behind but not within the cloud can be detected by radar waves which pass through the strips.

Window is often used in conjunction with electronic jamming transmitters to protect a formation of aircraft from radar controlled gunfire.

Rope is similar to window in that it is a confusion reflector, but it differs from it in length and also in the fact that it is untuned. Strips of rope are aluminum ribbons about 400 feet in length and about one-half inch in width. The ribbons are used as nonresonant reflectors for jamming low-frequency radars and are also employed in regions where the enemy operates many units which differ considerably in frequency. The rope material is dispensed in the form of a roll, one end of which is attached either to a small paper parachute or to a square of cardboard. The rolls equipped with parachutes assume a vertical position while falling and reflect waves that are vertically polarized. Those attached to cardboard squares unwind and float downward in a horizontal position, thereby reflecting horizontally polarized radar pulses.

ECM Test Equipment

Most of the test equipment used in the maintenance of ECM equipment is common to many other types of electronic equipment. The test equipment that may be considered special ECM test equipment is the RF signal generator(s) used to aline the ECM receivers.

Each generator used usually covers only one relatively small band of frequencies. Several generators are needed to maintain a complete set of ECM receivers. These RF generators (above VHF frequencies) produce various kinds of modulated RF signals. For example, continuous wave (straight RF), modulated-continuous wave (audio-tone modulated), or pulse modulation may be selected. With the tone modulation, various tone frequencies may be selected. With the pulse modulation, various pulse lengths and different pulse repetition frequencies (PRF) may be selected.

QUIZ

1. Electronic countermeasures consist of two general types of action. They are
   a. passive and deception
   b. deception and active
   c. active and passive
   d. reception and passive

2. A metallic foil called "window" is used
   a. to jam all types of electronic equipment
   b. only against radars
   c. to protect planes outside the window or pulse packet
   d. to simulate a moving target

3. Long-range air-search radar must use low PRF values
   a. to prevent breakdown voltage in the wave guide
   b. because the frequency of the radar is low
   c. because the pulse width is wide
   d. to obtain the desired range

4. The main purpose of ECM is to
   a. obtain navigational fixes from known enemy radar locations
   b. reduce the effectiveness of the enemy's electronic equipment
   c. deceive the enemy
   d. prevent the enemy from getting his signal through

5. Passive ECM can best be defined as
   a. the reception and evaluation of all signals
   b. rendering the equipment useless by jamming
   c. using window, rope, and chaff to confuse
   d. action taken to remain undetected

6. The AN/ALT-2 is a jamming transmitter that uses
   a. pulse modulation
   b. only amplitude modulation
   c. frequency modulation
   d. noise modulation

7. It is important to know the pulse width of a radar to determine the
   a. power output of the radar
   b. minimum jamming range
   c. minimum range of the radar
   d. length of the window to be used against the radar

8. To be effective, ECM must measure
   a. only vertically polarized signals
   b. only horizontally polarized signals
   c. both horizontally and vertically polarized signals
   d. signals of any polarization

9. Equipments used in the passive phase of ECM are
   a. APR-9, APA-74, and APT-5
   b. APR-4, pan adapter, and window
   c. Rope, AN/ALR-3, and APA-69
   d. APR-9, APA-74, and APA-69

10. The AN/APA-69 direction finder gives the direction of a radar signal by
    a. the oral null method
    b. displaying the signals on an "A" type scope
    c. displaying the signals on a PPI indicator with an engraved scale
    d. using a homing adapter to home on the signal

11. It is important to know the beam width and polarization of a radar to
    a. plan effective methods of jamming
    b. be able to receive the signal
    c. aid the operator in tuning
    d. set the jamming transmitter on frequency

12. Antennas used in ECM for search operation are
    a. highly directional and broad band
    b. broad band and cover a very wide frequency range
    c. motor driven, normal rotation 120 c.p.s.
    d. connected directly to the pan adapter

13. ECM direction finders can be used to
    a. obtain the azimuth and direction of the signal only
    b. determine pulse width and pulse repetition frequency accurately
    c. check the power output of the radar whose signal is received
    d. obtain bearing and range of radars by using several readings

14. ECM receivers in the 1,000-megacycle and above region use
    a. RF input amplifiers
    b. butterfly resonator circuits
    c. ganged tuning capacitors
    d. RF preselectors

15. Outputs that can be obtained from ECM Receiver AN/APR-9 are
    a. pulse width, frequency, and peak power
    b. frequency, PRF, and direction
    c. pulse width, PRF, and frequency
    d. audio and video

16. The AN/APA-74 is an ECM
    a. pulse analyzer
    b. direction finder
    c. PPI indicator
    d. receiver

17. The AN/APR-9 covers a wide frequency range by the use of
    a. untuned crystal detectors
    b. three plug-in tuning units
    c. four plug-in tuning units
    d. a wobbulator

18. Test equipment used with ECM equipment is
    a. also used with other electronic equipment
    b. used only for ECM equipment
    c. usually one signal generator that covers the entire frequency spectrum
    d. of the pulse-modulated type

19. The panoramic adapter is used principally
    a. to indicate modulation characteristics
    b. to measure PRF and PW
    c. to set jammers on frequency
    d. as a tuning aid

20. In the AN/APR-9 receiver the beat frequency oscillator is used for detecting
    a. CW emissions
    b. FM emissions
    c. pulse emissions
    d. MCW emissions only

21. The code name "rope," as associated with ECM, is described as
    a. strips of aluminum cut to one-half the wavelength of a specific frequency
    b. nonresonant reflectors for jamming low-frequency radars
    c. a long line used to suspend a false target
    d. a tuned reflector that presents only a vertically polarized reflected wave

CHAPTER 14

MAGNETIC AIRBORNE DETECTION EQUIPMENT

By the year 1941, it had become apparent that the airplane was a deadly antisubmarine weapon. This was true, even though search and detection at first depended solely on visual sightings. The development of radar extended the usefulness of airborne antisubmarine measures even further, making detection of a submarine possible at night or under poor visibility conditions. However, visual or radar detection was generally possible only when the submarine was surfaced. Thus, some method of detecting a submerged submarine from an aircraft was needed. The use of sound ranging equipment (sonar) was not feasible, because there was no direct contact between the fast-moving aircraft and water. From preliminary studies, it was concluded that the most feasible method of detecting a submerged submarine was to detect its disturbance of the local magnetic field of the earth.

Principles of Magnetic Detection

Light, radar, or sound energy cannot pass from air into water and return to the air in any degree that is usable for airborne detection. On the other hand the lines of force in a magnetic field are able to make this transition almost undisturbed because the permeability of water and air are practically the same. Consequently, a submarine lying beneath the ocean's surface, which causes a distortion (anomaly) in the earth's magnetic field, can be detected from a position in the air above the submarine. The detection of this anomaly is the essential function of MAD equipment.

MAGNETIC ANOMALY

The lines comprising the earth's natural magnetic field do not always run straight north and south. If traced along a typical 100-mile path, the field twists at places to east or west, and assumes different angles with the horizontal. Changes in the east-west direction are known as angles of variation, while the angle between the lines of force and the horizontal is known as the angle of dip. If the same lines are traced only a short distance, 300 feet for instance, their natural changes in variation and dip over such a short distance (short-trace) are almost immeasurable. However, short-trace variation and dip in the area of a large mass of ferrous (magnetic) material are considerably greater, and thus measurable. This is illustrated in figure 14-1. The dashed lines represent lines of force in the earth's magnetic field.

Part (A) shows the angular direction at which natural lines of magnetic force enter and leave the surface of the earth. Note that the angles of dip are considerably steeper in extreme northern and southern latitudes than they are near the equator. Part (B) represents an area of undisturbed natural magnetic strength. In parts (C) and (D), the submarine's magnetic field distorts the natural field as shown. The natural field's density is decreased in (C) and increased in (D). The natural angle of dip is also affected.

SATURABLE CORE MAGNETOMETERS

Before commencing this discussion of magnetometers, first become familiar with the contents of chapter 4 of this course, which discusses saturable-core devices. Special attention should be given to the meaning of hysteresis loops and the output waveforms of self-saturating devices.

The magnetometer, in its simplest form, consists of a coil wound on a core of highly permeable material, such as Permalloy. In operation, the coil is energized, or excited, by an alternating current. An additional required characteristic is that the exciting current be of sufficient magnitude to saturate the core material for a portion of each half cycle.

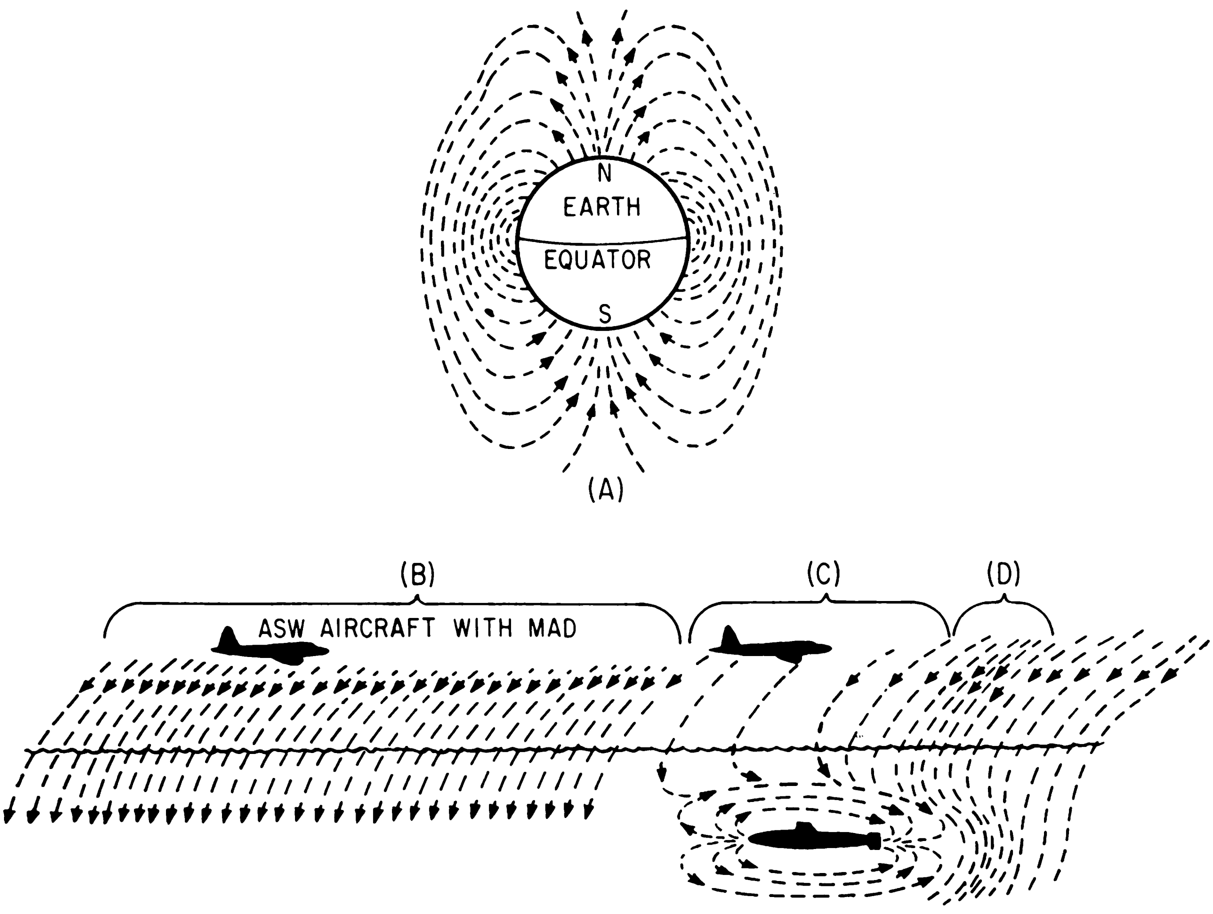


Figure 14-1.—Simplified comparison of natural field density and submarine anomaly.

That is, during each complete cycle the core is saturated once in one direction, and once in the opposite direction.

As pointed out in chapter 4 of this course, the inductive reactance of a coil at any instant depends on the degree to which its core has been magnetized up to that instant. When the core material saturates, the inductive reactance of its surrounding coil drops to a fraction of its presaturation value. In analyzing the effects of alternately saturating and desaturating a magnetometer's core, reference is made to figure 14-2.

Consider a simple single-coil magnetometer of the type mentioned, driven by a sinusoidal current source. Its inductive reactance, when saturated, is negligible. If the coil had very little inductive reactance (remaining saturated at all times for instance), its impedance to the input current would be only slightly more than its d-c resistance. Therefore, its voltage drop would be small and in phase with the exciting current. This condition is represented by curve ACEC'E'A' in figure 14-2 (A). Conversely, if the core were never saturated, the coil's inductive reactance would remain large. Therefore, its voltage drop would be large and out of phase (that is, leading) with the exciting current. This condition is represented by curve BDFD'F'B' in figure 14-2 (A). If the magnetometer shifted alternately between the two conditions, its voltage would obviously also shift alternately from one waveform to the other. As the magnetometer goes in and out of saturation during each half cycle, its coil voltage follows the path ACDFEC'D'F'E'A' shown in figure 14-2 (A). Note that the shift of form takes place each time wave A encounters the dashed lines representing the levels of saturation. The final waveform is shown in figure 14-2 (B).

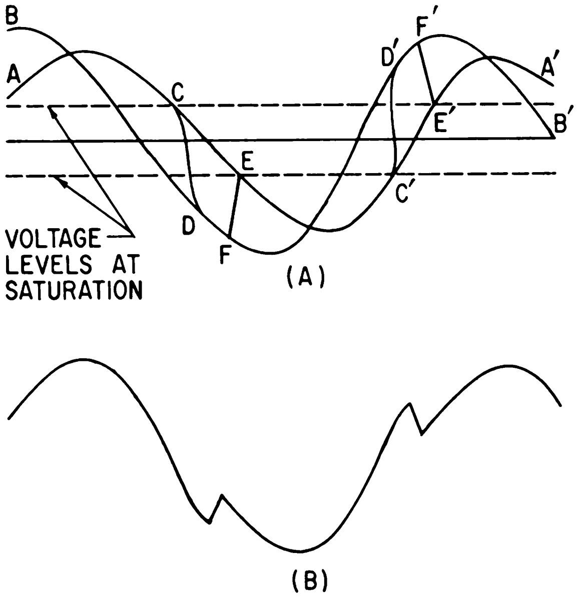


Figure 14-2.—Voltage waveforms across single-element magnetometer coil.

EFFECTS OF EXTERNAL FIELD ON MAGNETOMETER

Effects on Saturation

Up to this point, the effects of external magnetic forces as applied to magnetometers have not been mentioned, though the measurement of these effects is the prime function of MAD equipment. A discussion of these effects commences with reference to figure 14-3.

Part (A) depicts a single magnetometer element with its typical waveform in the absence of any external magnetic field. Saturation time is the same in either direction. In part (B), the same element has been placed in an external magnetic field, which represents the earth's natural magnetism. The magnetometer's core is thus seen to be partially magnetized by the external field. Obviously, the alternating magnetizing force of the coil will be aided by the externally induced core magnetism for one half cycle, and opposed by it in the next half cycle. As a result, the core will reach saturation sooner and desaturation later during the first half cycle, and saturation later and desaturation sooner during the next half cycle. Therefore, the waveform of the externally influenced magnetometer will appear as shown in (B) of the figure. The solid line portions of the waveform show where saturation takes place when there is an external field. The dashed portions show where saturation would have taken place had there been no external field.

Effects of Varying External Field Direction

The magnetometer element in figure 14-3 (B) is shown to be in perfect alinement with the external field. Under that condition, the external field is exerting its maximum influence on the magnetometer's waveform. Should the element be rotated to lie directly across the external field, there would no longer be any measurable effect caused by the external field. Thus, it becomes apparent that the magnetometer element's waveform is sensitive to the direction of the external field. It is also sensitive to the density, or strength, of the external field. Referring to figure 14-1, assume the ASW aircraft is at position (B). While flying through this undisturbed zone, the magnetometer's waveform is undisturbed. In zones (C) and (D), however, the changing density and dip angle of the external field will cause considerable changes in the magnetometer's waveform. Amplification and display of these changes are the prime functions of all MAD equipments.

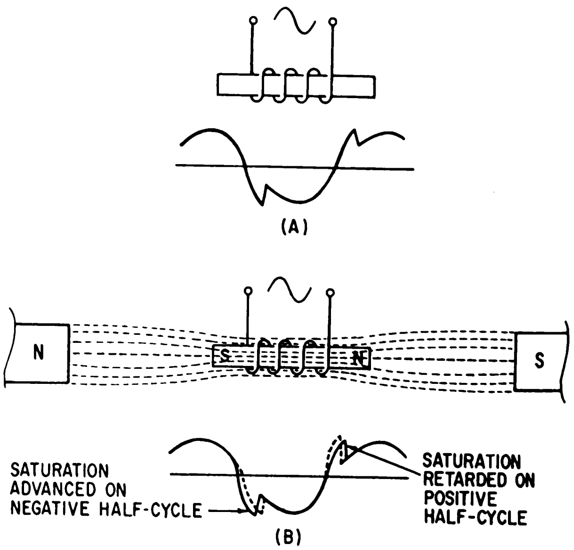

(A)
N
S
N
S
SATURATION ADVANCED ON NEGATIVE HALF-CYCLE
SATURATION RETARDED ON POSITIVE HALF-CYCLE
(B)

Figure 14-3.—Effects of external magnetic field on magnetometer.

MAGNETOMETER ORIENTATION

Aircraft Maneuver Error

In the course of an ASW flight, the aircraft must obviously make a number of maneuvers, such as turns, climbs, and descents. If a magnetometer were fixed rigidly to the airframe, its waveform would change every time a maneuver was performed. Among so many meaningless changes, a change signaling the proximity of a submerged submarine would easily be lost. Thus, it is necessary to install the magnetometer in rotatable mounts, and provide some means of automatically keeping it alined (oriented) in the external magnetic field, regardless of aircraft maneuvers.

Automatic Magnetometer Orientation

An automatically oriented magnetometer head is shown in figure 14-4.

Magnetometers 1-1 and 2-2 are orientation-sensing magnetometers. These magnetometers seek to rest directly across the external field (as shown in the figure) at all times. They are connected as pairs, each pair in a separate bridge circuit, for greatest sensitivity. When they are not directly across the external field, their waveforms are distorted in the manner already discussed. This waveform distortion triggers an amplifier-modulator and servomotor. The servomotors turn the appropriate rotary drives until each pair is once more in its cross-field, or null, position. In this way, the detecting magnetometer (DM) in figure 14-4 is maintained in external-field alinement at all times, regardless of aircraft maneuvers. This eliminates some of the meaningless signals caused by aircraft maneuvers. Consequently, those signals caused by sudden changes in the external field will be easier to detect.

THE MAGNETOMETER BRIDGE

A more sensitive detector head is obtained by using two, rather than one, magnetometer elements. They are connected in a bridge and labeled $L1$ and $L2$, as shown in figure 14-5 (A).

The elements are wound in series opposing but are identical in all other respects. When no external field is present, their series-connected voltage drops are equal and in phase at all times. Therefore, their difference voltage appearing across $X1$ and $X2$ is zero. Now, assume an external field exists as shown in figure 14-5 (A). As a half cycle of voltage rises in the secondary of $T1$, with its polarity as marked, the series current through $L1$ and $L2$ induces a rising electromagnetism in their respective cores with the polarity shown. Note that the electromagnetic polarity of $L1$ is opposed by the external field, while that of $L2$ is aided by the external field. Obviously, $L2$ will saturate first. Assuming the impedance of $L2$ to be zero when saturated, all the voltage developed in the lower half of $T1$ secondary appears between $X1$ and $X2$ momentarily. When $L1$ also saturates, a split second later, its coil is effectively shorted and the bridge is again balanced so that the voltage between $X1$-$X2$ is zero. Thus, the brief time interval between the saturation of $L1$ and that of $L2$ produced a "spike" of voltage across $X1$ and $X2$ with the polarity shown. In the next half cycle, $L1$ will saturate first, but the output polarity of secondary $T1$ will also have reversed, and another positive spike will be generated. Figure 14-5 (B) shows the series of positive spikes across $X1$ and $X2$. The magnitude (height) of these spikes is relative to the strength of the external field.

The actual percentage of change in the earth's field in a particular area, caused by a submarine, is extremely small. If the full strength of the earth's field were allowed to affect the magnetometer at all times, the relatively tiny submarine anomaly changes would probably go undetected. However, if all but a tiny part of the earth field effects were eliminated, the anomaly changes would then be a much larger part, percentage wise, of the remainder. The anomaly would thus be more easily detected. In practice, the earth field effects are eliminated to any desired extent by using an adjustable d-c bias voltage. This voltage (E_{DC}) acts through the magnetometer coils as shown in figure 14-6 (A) and (B).

In (A), note that the induced polarity of $L1$, due to the exciting current L_{AC}, is in opposition to the direction of the external field, while the induced polarity of $L2$ is aided by the external field. However, the tendency of E_{DC} is to oppose the external field in both coils. Thus, E_{DC} boosts the opposition of $L1$ to the external field, while it decreases the extent to which $L2$ is aided by the external field. In (B), the voltage of $T1$ has reversed, but E_{DC} remains constant. Consequently, $L1$ is now aided by the external field, and $L2$ is opposed. Again, however, the opposing coil is boosted by E_{DC},

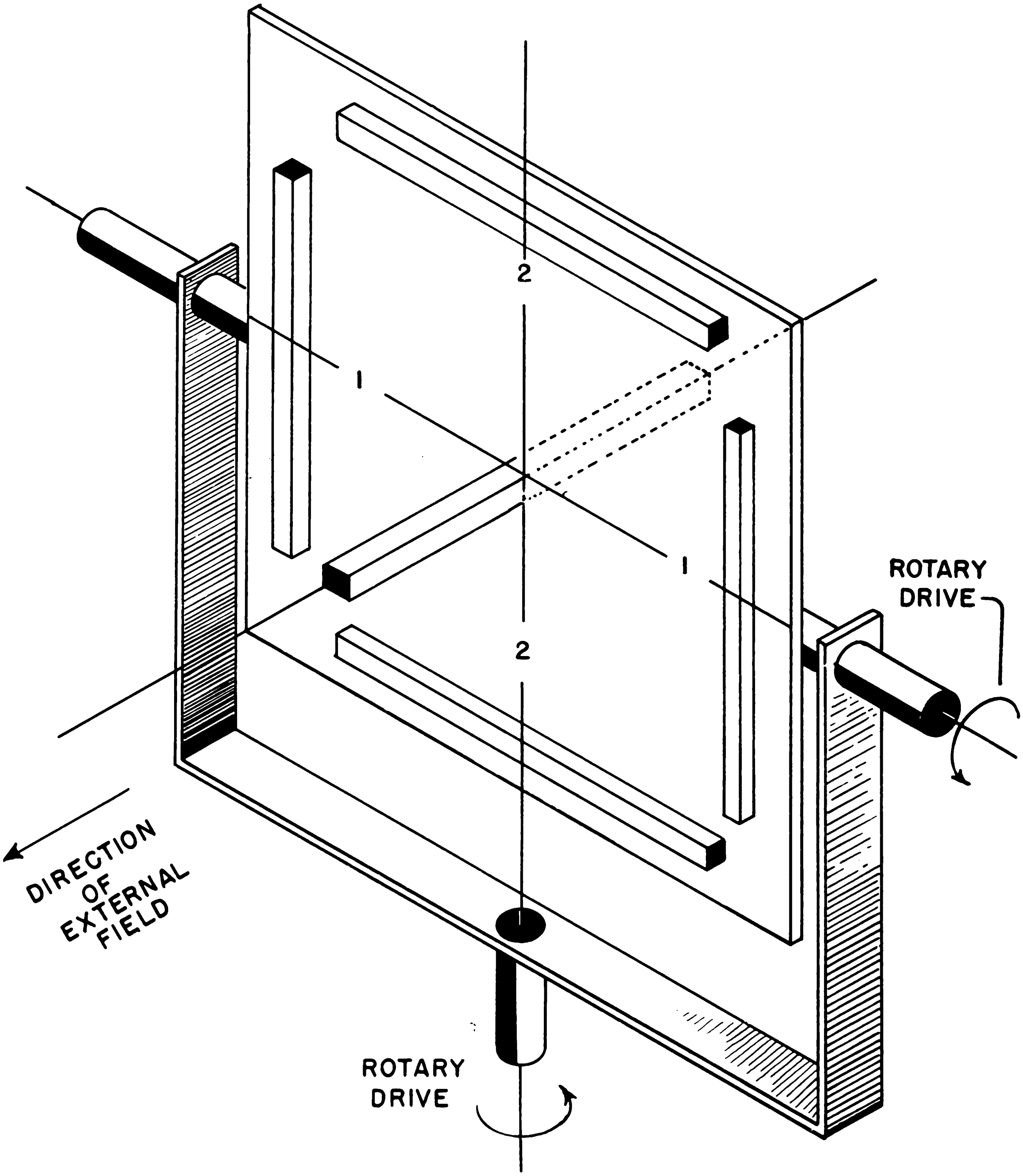


Figure 14-4.—Automatically oriented magnetometer head.

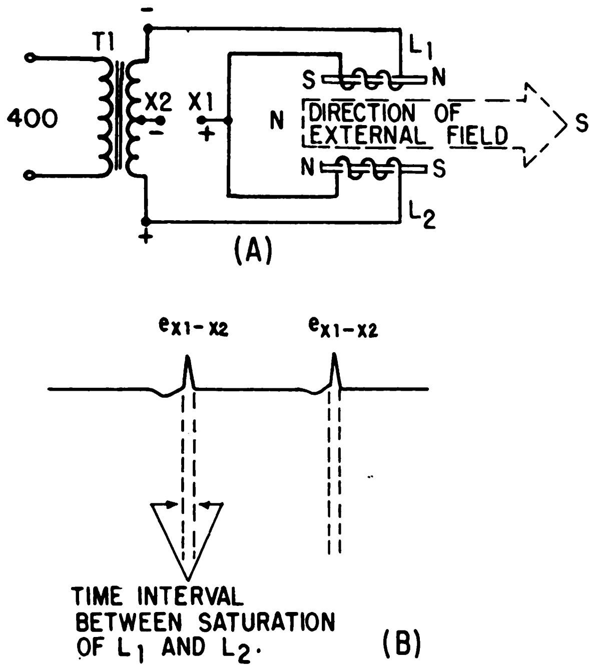

T1
400
X2
X1
L1
S
N
DIRECTION OF EXTERNAL FIELD
N
S
L2
(A)
ex1-x2
ex1-x2
TIME INTERVAL BETWEEN SATURATION OF L1 AND L2.
(B)

Figure 14-5.—Magnetometer bridge and its waveforms.

while the aiding coil strength is decreased. Through the foregoing process, E_{DC} counteracts the effects of the external field on the magnetometer waveform. By increasing E_{DC}, the magnitude of the output spikes caused by the external field is reduced.

Part (C) of figure 14-6 represents magnetometer output spikes caused by an external field when E_{DC} is zero. In part (D), E_{DC} is used to reduce the spikes to an operating level which permits the detection of submarine anomalies. In (E), the spike magnitudes refer to figure 14-1. Spikes 1, 2, and 3 represent the adjusted operating magnetometer output when the ASW aircraft is flying through zone (B) of figure 14-1. When the aircraft enters zone (C), where the anomaly has decreased the external field density, spike magnitude is likewise decreased, as shown by spikes 4, 5, and 6. In zone (D), external field density is greater than its normal value, so spikes 7, 8, and 9 are of greater magnitude. Thereafter, the spikes will resume their normal magnitude. The magnetometer spike magnitudes comprise the intelligence that is amplified and displayed to the MAD operator.

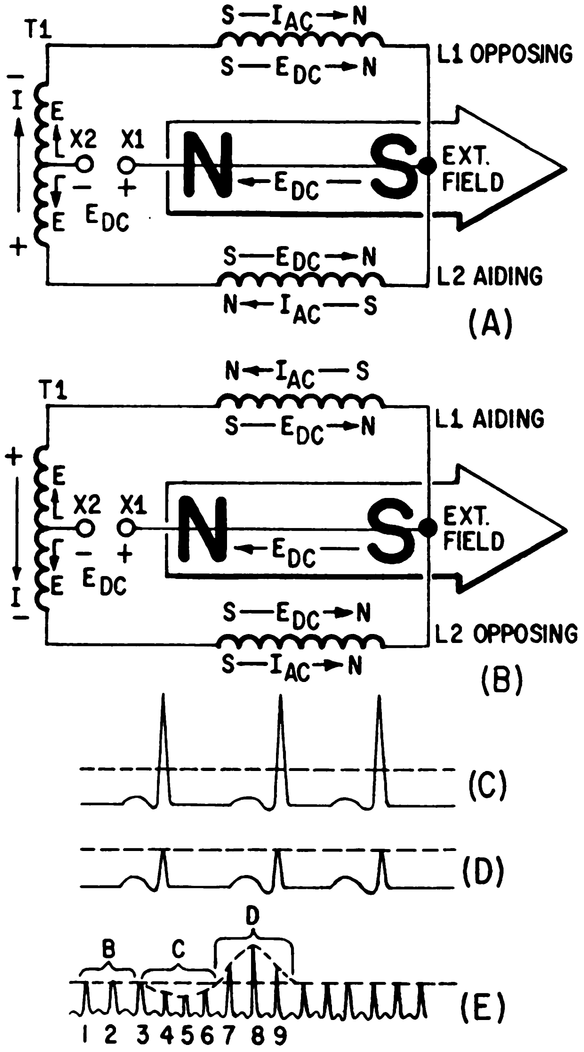


Figure 14-6.—Effects of bias voltage on magnetometer output.

The Submarine Anomaly

PROBLEMS OF DETECTION

The greatest range at which a submarine may be detected is a function of both the intensity of its magnetic anomaly and its distance from the detector, assuming a fixed detector sensitivity.

A submarine's magnetic moment, which determines the intensity of its anomaly, is dependent mainly on its alinement in the earth's field, its size, the magnetic latitude at which it is detected, and the degree of its permanent magnetization. As already stated, the distance between detector and submarine is also of prime importance. This is true because the strength of a magnetic field varies as the inverse cube of the distance from the field's source. That is, if the detectable strength of a magnet has a given value at a given distance and the distance is doubled, the detectable strength of the magnet at the increased distance will then be one-eighth of its former value. From the foregoing at least two facts become clear. First, MAD equipment must be operated at a very low altitude to gain the greatest proximity possible to enemy submarines; and second, the searching aircraft should fly at a predetermined speed and follow an established search pattern. This insures systematic and thorough searching of the prescribed area so that no existing anomalies are missed.

ANOMALY STRENGTH

Up to this point, the inferred strength of a submarine's anomaly has been exaggerated, for purposes of explanation. Its actual value is usually so small that MAD equipment must be capable of detecting a distortion of approximately one part in 60,000. To further clarify this point, the direction of the earth's magnetic vector field is rarely changed more than one-half of one degree in a submarine anomaly.

Figure 14-7 (A) represents a contour map showing the degree of anomaly caused by a typical submarine. The straight line is approximately 800 feet in length and represents the flight path of a searching aircraft through the submarine anomaly. If the submarine were not present, the undisturbed magnetic intensity of the area due to its assumed natural characteristics, would be 60,000 gammas. (The gamma, symbolized by the Greek letter γ, is a measure of magnetic intensity.) All variations in the anomaly, when the submarine is present, would then be above or below this natural intensity. Therefore, 60,000 gammas is the zero reference drawn in the diagram.

Starting with the aircraft at point A, where the anomaly is undetectable, the earth's field concentration rises thereafter to an intensity of 2γ (60,002) at B. Its intensity increases further, until a peak value of 45γ is reached at C. From that point it decreases to zero at D. Beyond D, a zone of what amounts to magnetic rarification is encountered. The earth's field is less intense than its normal value. Consequently, anomalous values in this zone are considered as "minus" quantities. A peak minus "intensity" is reached at point E, and thereafter rises back to its normal, or undetectable, intensity at point F.

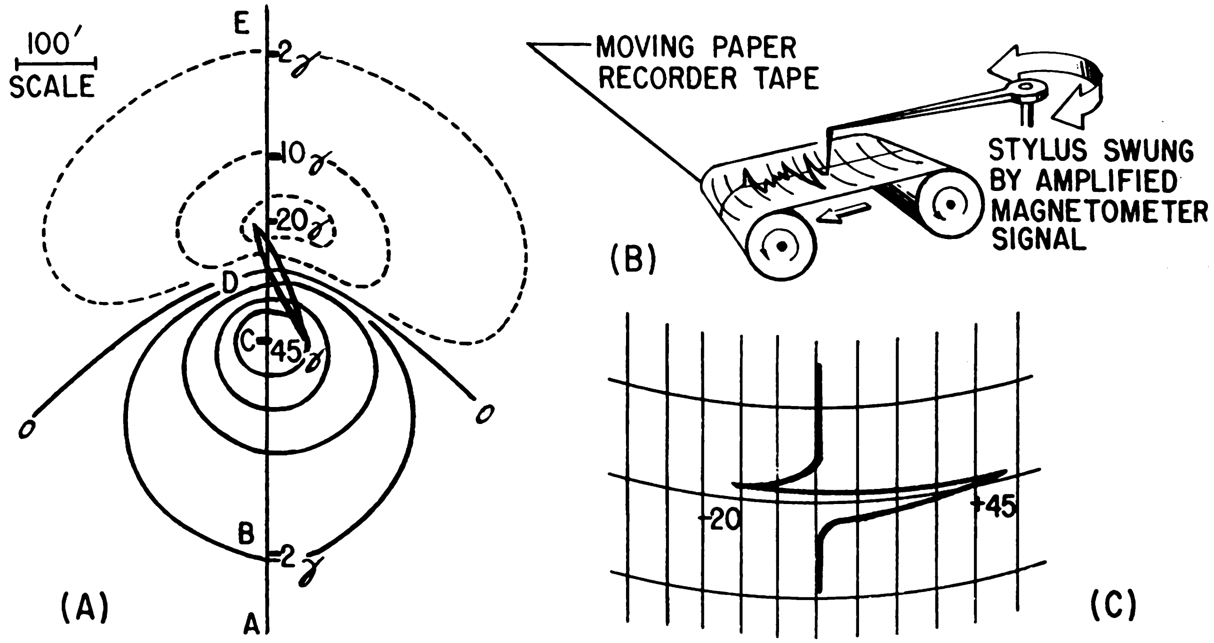


Figure 14-7.—(A) Degree of anomaly; (B) anomaly recorder; (C) sample anomaly record.

As the varying degrees of intensity are encountered, they are amplified and used to drive a swinging stylus, as shown in figure 14-7 (B). The tip of the stylus rides against the moving paper tape, leaving an ink trace. It is swung in one direction for positive γ, and in the opposite direction for negative γ. The magnitude (arc length) of its swing is determined by the intensity of the anomalous signal. Figure 14-7 (C) is a sample of paper recording tape, showing the approximate trace caused by the anomaly in part (A).

In the illustration just given the search aircraft's altitude was 200 feet. At a lower altitude, the anomaly would have been stronger, and at a higher altitude it would have been weaker.

The orientor servo system will not react to a typical submarine anomaly. This is true because the orientor magnetometers are alined perpendicularly to the earth's field. The triggering threshold of the orientor is designed to be well above the level of distortion caused by a typical submarine anomaly. It will react quickly, however, to minute changes in the direction of the relatively powerful earth field, such as would be caused by aircraft maneuver.

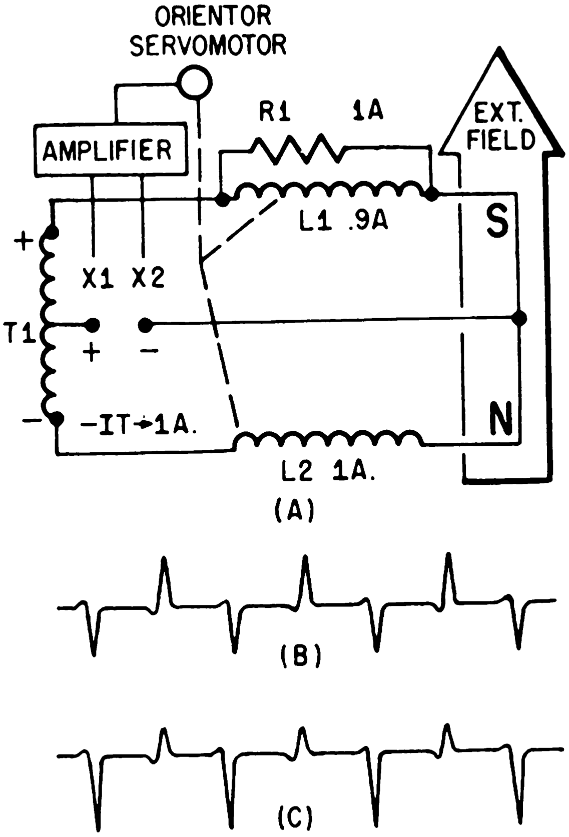


Figure 14-8.—Orientor magnetometer bridge.

ORIENTOR MAGNETOMETER OPERATION

As previously stated, the purpose of the orientor magnetometers is to maintain the detector magnetometer in alinement with the earth's field at all times. In doing so, the orientors maintain themselves across the earth field.

Figure 14-8 represents a simplified orientor bridge circuit. Since no two magnetometers are perfectly matched, one of them, $L1$, is purposely unbalanced by $R1$. The unbalanced output at $X1$ and $X2$ is then used as the error intelligence to drive the orientor servomotors. The magnitude of the unbalanced output is great enough to overshadow the magnetometer coil mismatch errors and relatively small submarine anomalies. The orientor servo loop reacts only to misorientation in the earth field, because only a slight displacement in the powerful earth field will cause a detectable change in the orientor's normal output. (See fig. 14-8.)

In part (A) the magnetometers are shown to be across the earth's field, and thus are unaffected by it. In explaining the crossfield, or null, output of the magnetometers, assume that the saturation current for either coil is one ampere. When the total series exciting current I_t rises to one ampere, $L2$ saturates. However, part of this current is bypassed around $L1$ through $R1$. Thus, $L1$ always saturates later, due to its unbalancing resistor.

With the $T1$ polarity shown in part (A), there will be a negative spike of voltage at $X2$ between the saturation times of $L2$ and $L1$. On the next half-cycle, $L2$ will again saturate first. Since the polarity of $T1$ will have reversed, a positive spike will be generated at $X2$. Thus, the normal crossfield output of the orientor magnetometers is a series of equal-magnitude negative and positive spikes, as shown in part (B). As long as these spikes are of equal magnitude, the servo loop will not react. When the magnetometers move out of their crossfield position, the external field will affect their output. Depending on direction, the saturation of $L2$ will be retarded during one half-cycle and advanced on the next.

Consequently, the saturation-time interval, which affects the positive and negative spikes, will be changed. It will be shortened on one half-cycle and lengthened on the other. As a result, the spikes will be of unequal magnitude, as shown in (C) of figure 14-8. The unequal-magnitude spikes trigger the servo system, which repositions the orientor magnetometers to their zero, or crossfield, position.

The detector head has three axes of movement, since it is mounted within three gimbals. The inner and outer gimbals are each controlled by a pair of orientor magnetometers which are mounted on the same plate that holds the detector magnetometer. The third axis gimbal detector is a "coarse" positioner. It derives its signal by comparing the relative positions of the inner gimbals, and also the relative positions of the third gimbal and frame.

Magnetic Noise and Compensation

NOISE SOURCES

In and around every aircraft there are troublesome magnetic fields that cannot be eliminated. Many of these fields are of sufficient strength to seriously impair the operation of MAD equipment. Consequently, some means must be employed to either compensate for these fields or cancel them.

The fields themselves cannot conceivably be eliminated but their effects may be cancelled or greatly reduced by the use of variable-strength electromagnets placed in the vicinity of the magnetometer head.

The noise fields fall into four general categories: (1) permanent aircraft fields; (2) induced aircraft fields; (3) eddy-current fields; and (4) electromagnetic fields.

The permanent aircraft magnetic field is produced by steel parts in the aircraft that have attained some degree of permanent magnetization. Common sources of this type field are steel members in the engine, landing gear, and airframe. This field is generally constant in its strength and direction, and is not largely affected by the aircraft's heading or maneuvers.

The induced magnetic field in an aircraft is caused by the concentration of natural magnetic lines of force in various ferromagnetic parts. This type of field could be thought of as the "aircraft anomaly." Generally it is not fixed in its strength or direction, but changes each time the aircraft changes magnetic heading. This type of field also varies with magnetic latitude. In addition, it may vary with any change of ordnance load. For instance, it will often undergo a considerable change when the bomb load, with its ferromagnetic mass, is loaded or released.

Eddy-current fields are mainly produced by aircraft maneuvers. An aircraft in flight actually constitutes a simple electric generator. That is, the three essential ingredients for generating an electric current are present—conductors, a magnetic field, and motion. The motion of the aircraft through the earth's field induces eddy currents in its conducting structures. In some instances, eddy current field disturbances can completely mask the presence of a submarine anomaly.

Electromagnetic fields are caused by the normal flow of current through the conductors and skin-return paths of the aircraft. They vary as loads are turned on or off. In a steady-state condition (no loads being added or removed in the aircraft power system), electromagnetic fields are constant, and have much the same characteristics as the permanent field.

COMPENSATION

Regardless of its source, strength, or direction, any magnetic field may be defined in terms of three axial coordinates. That is, it must act through any or all of three possible directions—longitudinal, lateral, or vertical—in relation to the magnetometer detector.

Stray fields from a number of sources may exist in the magnetometer's area, but their total effect may be regarded as a single vector field. Consider this single vector as being comprised of three subvectors. These subvectors are merely the total field's components which lie along the aircraft's longitudinal, vertical, and lateral axes.

Electromagnetic coils are used for compensating the stray fields around the magnetometer head. Three coils are placed in the vicinity of the magnetometer head, and each is mounted as shown in part (A) of figure 14-9.

Each coil is mounted so that its magnetic axis is alined with one of the three subvectors

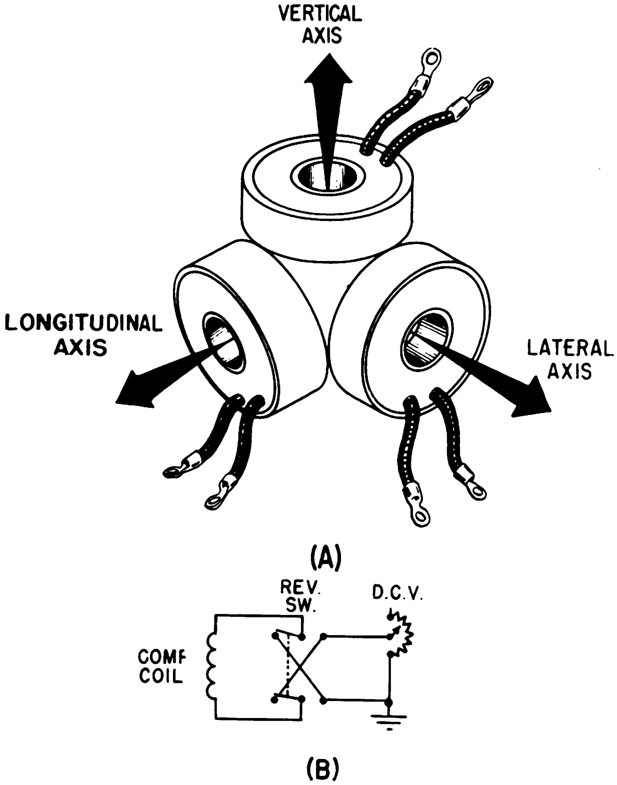


Figure 14-9.—(A) Arrangement of compensating coils; (B) compensating coil circuit.

of the stray field. By setting the direction and intensity of current through each coil, each stray field subvector is balanced out by its opposing coil. A single compensating coil circuit is shown in figure 14-9 (B). The circuits for all three coils are identical. Current direction (and thus, bucking field direction) is controlled by the reversing switch. Current intensity (bucking field strength) is controlled by the potentiometer.

Under ideal conditions, all magnetic fields tending to act on the magnetometer head would be completely counterbalanced. In this state the effect on the magnetometer is the same as if there were no magnetic fields at all. This state exists only when the following ideal conditions exist:

1. The aircraft is flying a steady course (no maneuvers) through a magnetically quiet geographic area.
2. Electric or electronic circuits are not turned on or off, during compensation.
3. The proper d-c bucking current has been set through the magnetometer, so that the earth magnetism is almost canceled.
4. Direct current of the proper intensity and direction has been set through the compensating coils, so that all stray fields are balanced.

To meet these conditions approximately, the compensation of MAD equipment is performed in flight usually well at sea. In this way the equipment is compensated under operating conditions which closely resemble those of actual ASW search flights.

From the foregoing, it is seen that the essential objective of compensation is to gain a state of total balance of magnetic forces around the magnetometer. Thereafter any sudden shift in one of the balanced forces (such as an anomaly in the earth-field force) upsets the total balance. This unbalance is indicated on the recorder. Unfortunately, however, a shift in any of the balanced forces will be indicated. Shifts in any of the forces other than the earth field are regarded as noises. Such shifts are caused by changes in heading (changes in induced magnetic field), maneuvers (causes eddy-current fields), changes of electric loads (changes electromagnetic field), and natural earth-field variations, if sufficient in magnitude.

With so many variable influences, MAD compensation is obviously complicated. The only purpose of this section has been to acquaint you with the principles of cause and effect as applied to MAD compensation. The actual compensating procedure is discussed more fully in the service manuals for specific equipments, such as the AN 16-30ASQ8-3, which is the *Handbook of Maintenance Instructions* for the ASQ-8 MAD equipment.

Typical MAD Equipments

ASQ-8 MAD SET

A complete description of the functional details, circuitry, and operating capabilities of any set of MAD equipment is beyond the intended purpose of this chapter. Also, much of this information is classified. For these reasons, the description of a typical MAD set is limited to a list of its units and the general functions and physical appearance of each unit.

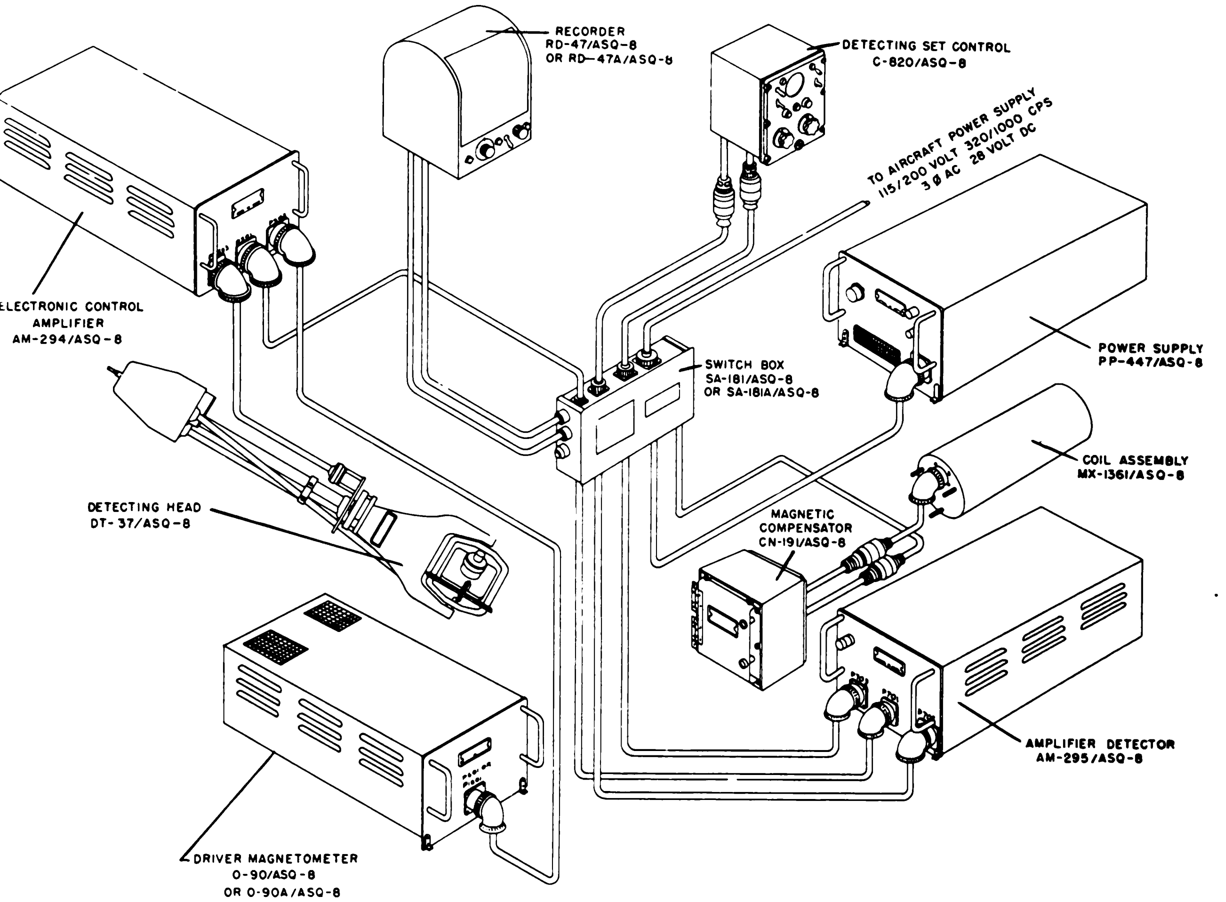


Figure 14-10.–Units of an ASQ-8 MAD set.

The units of the ASQ-8 MAD equipment are sted and shown in figure 14-10. A functional scription of each unit follows.

itch Box

Switch box SA-181/ASQ-8 contains the main phase power relay, fuses, and special tools maintenance of the ASQ-8. It serves as central junction box between other units, d also as the tie-in point for auxiliary gear. Switch box SA-181A/ASQ-8 is newer, aller, and lighter. It is similar to the other x except that it contains spare fuses, but not special tools.

wer Supply

Power supply PP-447/ASQ-8 contains a phase rectifier circuit, an electronic voltage gulator, and a time-delay starting circuit. is unit supplies the B+ and filament voltages all other units of the set.

Magnetometer Driver

The Magnetometer Driver 0-90/ASQ-8 contains a 400-cycle master oscillator, and a driving amplifier for each of the orientor magnetometers and the detector magnetometer. It also supplies power to the fixed fields of the 2-phase orientor servomotors. Driver 0-90A/ASQ-8 contains all of the foregoing plus a 28-volt d-c cooling blower.

Control Amplifier

Electronic Control Amplifier AM-294/ASQ-8 contains the 400-cycle amplifier channels which detect orientation errors and in turn drive the variable fields of the orientor servomotors to reposition the magnetometer head. It also provides receptacles for connecting the Magnetic Detector Test Set TS 701/ASQ, voltage test jacks, and a north-south hemisphere selector switch.

Detecting Head

The Detecting Head DT 37/ASQ-8 contains the detector and orientor magnetometers on one end, and the orientor servomotors in a housing on the opposite end. Connecting linkage and mounting facilities lie between.

Amplifier Detector

The Amplifier-Detector AM-295/ASQ-8 contains an 800-cycle selective amplifier, which is sensitive to the detector magnetometer waveform. It also contains a very-low-frequency amplifier which drives the recorder in accordance with signals derived from the detector-selective amplifier output.

Recorder

The MAD Recorder RD 47/ASQ-8 contains two 0.5-0-0.5 center-scale milliammeter movements, each driving a recording pen, or stylus. Each may record simultaneously on a moving paper chart. Chart speed is variable in ten steps from 3/4 inch per hour to 12 inches per minute. Each movement is independent of the other, so that the MAD operator may observe and compare two separate MAD signals.

MAD Recorder RD 47A/ASQ-8 is the same as the other, except that the chart speed is variable in four steps from 0.2 inch per minute to 12 inches per minute. Both recorders have their own controls for pen-zero setting, chart speed, and an illumination rheostat.

Detecting Set Control

The Detecting Set Control C-820/ASQ-8 contains all controls and indicators for normal MAD operation, except those located on, and used exclusively for, the recorder. The detecting set controls and their functions are listed as follows:

1. PWR (Power) is the main ASQ-8 on-off control switch. It controls power flow to the Power Supply PP447/ASQ-8.
2. SENS. (Sensitivity) adjusts the gain of the detector circuit in the Amplifier Detector AM-295/ASQ-8. This is to obtain recorder pen deflections of a convenient magnitude.
3. OUTPUT BALANCE adjusts the recording pen to its zero (center-chart) position, with SENS. set at zero.
4. EARTH FIELD BALANCE controls the d-c earth field-bucking current impressed through the detector magnetometer coils.
5. RESIDUAL FIELD meter indicates values selected by the METER switch.
6. METER switch—Its normal position is RESFLD (residual field). In this position, it causes the residual field meter to indicate the desired minute (residual) portion of the earth field around the magnetometer that is not bucked out. In the METER position, the switch will cause the meter to indicate B+ voltage. In the BAT position, the meter indicates the magnetometer bias voltage.
7. TEST SIG (test signal) provides test signals of 0.5 gamma in the up position, or 5 gammas in the down position.
8. SIG-SHORT (normal signal or shorted signal). In the up (SIG) position, normal magnetometer signals are connected in the set. In the down (SHORT) position magnetometer signals are shorted. The TEST SIG and SIG-SHORT switches are used mainly for maintenance, checking, or troubleshooting.

Magnetic Compensator

Magnetic Compensator CN 191/ASQ-8 contains all adjusting controls for varying the strength and direction of d-c current through the three compensating coils. The controls are: coarse and fine attenuators, reversing switches, and HI-LO current range selectors, one of each for each coil.

Coil Assembly

Coil Assembly MX 1361/ASQ-8 contains the three air-core coils, mounted mutually perpendicular and used for compensation.

ASQ-10 MAD SET

The ASQ-10 MAD set is designed for the same purpose, but to replace, the ASQ-8. It is both smaller and lighter, as shown in tables 14-1 and 14-2. Its basic operating principles are the same, but its physical appearance is quite different in some respects. Many units which are separate in the ASQ-8 are combined compactly in the ASQ-10.

As it comes from the manufacturer, the Magnetic Detecting Set AN/ASQ-10 consists of three major units, the Detecting Set Control C-2548/ASQ-10, the Detecting Head DT-37B/ASQ-8, and the Amplifier-Power Supply

Table 14-1.—Functional comparison by units.

AN/ASQ-8	AN/ASQ-10
Electronic Control Amplifier AM-294/ASQ-8	Amplifier-Power Supply AM-1967/ASQ-10
Driver Magnetometer 0-90/ASQ-8	Amplifier-Power Supply AM-1967/ASQ-10
Amplifier Detector AN-295/ASQ-8	Amplifier-Power Supply AM-1967/ASQ-10
Power Supply PP-447/ASQ-8	Amplifier-Power Supply AM-1967/ASQ-10
Switch Box SA-181/ASQ-8	Not required
Detecting Set Control C-820/ASQ-8	Detecting Set Control C-2548/ASQ-10
Detecting Head DT-37A/ASQ-8	Detecting Head DT-37B/ASQ-8
Recorder RD-47/ASQ-8	Recorder RO-32/ASQ-10 (not included as a unit of the AN/ASQ-10)

Table 14-2.—Physical comparison.

	AN/ASQ-8	AN/ASQ-10
Total weight of unit boxes	150 Lbs.	31.6 lbs.
Total volume	7,700 cu. in.	1,200 cu. in.
Number of unit boxes	6	2
Units of test equipment required	2	2
Number of vacuum tubes	44	16
Power consumption	700 watts	117 watts

AM-1967/ASQ-10. In the fleet, either of two recorder types may be used with the ASQ-10.

Detector Head

The AN/ASQ-10 employs the DT-37B/ASQ-8 detecting head which is a slightly modified version of the DT-37A/ASQ-8 employed by the AN/ASQ-8. Changes from the DT-37A/ASQ-8 include a protective fiberglass covering surrounding the detecting element of the DT-37B/ASQ-8 Detecting Head. In addition, the inner and outer unbalance resistors have been removed from the head and installed in the Amplifier-Power Supply.

Detecting Set Control

The Detecting Set Control C-2548/ASQ-10 contains the controls necessary for inflight operation of the AN/ASQ-10. It incorporates a power switch, a meter displaying system voltages, a switch combining the functions of meter switch and sensitivity control, a test switch, and orientation balance controls. The Detecting set Control also provides a d-c bias circuit for balancing the earth's magnetic field.

The operating controls, located on the Detecting Set Control, and their functions are as follows:

PWR: The main power switch.
RESIDUAL FIELD: A meter for reading equipment voltages.
TEST: A test signal switch.
FUNCTION: A function selector switch.
EARTH FIELD BALANCE: A rheostat for control of balance current in the detector magnetometer.

I ORIENT AND O ORIENT: Orienting controls for the inner and outer gimbal systems.

New features incorporated in the Detecting Set Control include combination of the sensitivity control with the FUNCTION switch. This is a 12 position switch with no end stops and allows a reduction in overall unit height of 1-1/8 inches. The Earth Field Balance potentiometer was changed from 45 to 48 steps to provide a more uniform 1,000 gamma-per-step graduation.

Knobs have been added to the orientation potentiometers so that they may be adjusted by hand. The use of 4-turn potentiometers decreases the sensitivity of the orient adjustment. Also a push type Test Switch has been provided for the convenience of the operator and the bias battery of the AN/ASQ-8 has been replaced with a Zener voltage supply.

Amplifier-Power Supply

The Amplifier-Power Supply, AM-1967/ASQ-10 contains a voltage rectifier and electronic regulator for the 300-volt d-c supply, a 28-volt d-c filament supply, a North-South latitude switch, servo gain controls, spike adjustment controls, a cooling fan, and a protective fuse for the power source. Facilities for the following five plug-in subassemblies are also contained in this unit: Magnetometer Amplifier; Magnetometer Oscillator and Filament Supply Regulator; Third Axis Amplifier; Inner Gimbal Amplifier; and Outer Gimbal Amplifier.

Some of the new features incorporated into the Amplifier-Power Supply are as follows: A servo switch on the Amplifier-Power Supply front panel opens both servo loops to facilitate the use of the AN/ASM-6 Test Set. A test plug has been installed on the front panel of the Amplifier-Power Supply to provide for AN/ASM-6 connections. The 28-volt d-c requirements of the AN/ASM-6 must be supplied directly from the aircraft installation since it is not available through the AN/ASQ-10 equipment.

The servo gain potentiometers and spike adjusting potentiometers are located on the front panel. Finger grip type fuse holders are also provided on the front panel. Transistorized control d-c heater regulator circuitry is employed for noise sensitive stages.

Keyed plug-in units secured with 1/4-turn type fasteners are used. This insures that only the proper subassembly can be installed in place in the Amplifier-Power Supply. An improved type North-South (latitude) switch has been installed.

A sensitivity adjustment is located on the magnetometer amplifier.

Recorder

Either the RD-47/ASQ-8 or the RO-32/ASQ-10 recorder may be used with the AN/ASQ-10 Magnetic Detecting Set. The new RO-32/ASQ-10 recorder utilizes a ball point pen. The recorder is lighter, more compact, and has improved vibration characteristics. The function and operation of the new recorder, however, is the same as that of the RD-47/ASQ-8.

QUIZ

1. Compensation of the permanent magnetic field of the aircraft is accomplished by
    a. passing a d-c current through the aircraft
    b. placing variable strength magnets near the magnetometer head
    c. placing variable strength magnets near the field
    d. passing an a-c current through the magnetometers

2. A source of energy that can pass readily from air to water and return is
    a. light
    b. sound
    c. magnetic
    d. radiofrequencies

3. With an aiding field, the magnetometer core will saturate how many times for each input cycle?
    a. One
    b. Two
    c. Three
    d. Four

4. In a balanced bridge magnetometer, the elements are wound
    a. series aiding
    b. series opposing
    c. parallel aiding
    d. parallel opposing

5. A magnetic anomaly is due to
   a. permeability of air
   b. permeability of water
   c. distorted earth field
   d. distorted submarine field

6. With an external field present, the output of the detector magnetometer will be
   a. negative spikes
   b. zero
   c. positive spikes
   d. positive and negative spikes

7. In the output of a detector magnetometer, the magnitude of the spikes is relative to the
   a. strength of the external field
   b. type of magnetic core material
   c. rate of change in aircraft attitude
   d. aircraft's position

8. For best possible results, compensation is done
   a. on the ground, away from buildings
   b. in flight, well at sea
   c. in flight, over level ground
   d. in the hangar

9. The following condition applies to the saturable inductor when the magnetometer core becomes saturated. Its
   a. reactance is maximum
   b. reactance is minimum
   c. d-c resistance is maximum
   d. d-c resistance is minimum

10. In the null position, the displacement of the orientor magnetometer in relation to the external field is
   a. 0°
   b. 45°
   c. 90°
   d. 60°

11. If the distance from a magnetic field is doubled, its detectable field strength becomes
   a. one-half
   b. one-fourth
   c. one-eighth
   d. one-sixteenth

12. The angle at which the magnetic lines of force leave or enter the earth's surface is called
   a. variation angle
   b. deviation angle
   c. dip angle
   d. departure angle

13. The unit of magnetic field strength measurement used in antisubmarine detection is the
   a. oersted
   b. gilbert
   c. gamma
   d. maxwell

14. The permanent aircraft magnetic field is produced by
   a. d-c current in the aircraft
   b. the earth's magnetic field
   c. the a-c generator
   d. steel in the aircraft

15. The magnetometer core normally has
   a. high resistance
   b. low resistance
   c. high permeability
   d. low permeability

16. The orientor magnetometers react to changes in
   a. earth field strength
   b. submarine field strength
   c. aircraft attitude
   d. submarine attitude

17. The induced magnetic field
   a. is fixed and does not vary
   b. causes permanent magnetization of steel in the aircraft
   c. changes with various aircraft loads
   d. is not affected by changes in aircraft loads

18. An aiding external field
   a. increases magnetometer reactance
   b. decreases magnetometer reactance
   c. increases saturation level
   d. decreases saturation level

CHAPTER 15

AIRBORNE SONAR AND SONOBUOYS

Presently, one of the major problems facing the Navy is the detection of enemy submarines. Detection may be accomplished by SONAR (SOund Navigation And Ranging), sonobuoys (expendable sonar sets), and MAD (Magnetic Air Detection) equipment. Sonar equipment is used by aircraft, surface ships, submarines, and harbor defense installations. The discussion that follows will relate to airborne sonar. Chapter 14 of this training course discusses MAD equipment.

Airborne Sonar

Aircraft using sonar equipment can quickly search a vast area of the ocean, and represent a very effective countermeasure to the submarine menace.

Basically the operating principle of sonar equipment is similar to that of radar, except that ultrasonic sound waves are used instead of radiofrequency waves. When sound-wave energy strikes an object, the object reflects a portion of that energy back to the source from which it came. Since the speed of the sound wave and the time it takes to travel out and to return are known, the range can be calculated. By knowing the direction from which the sound-wave echo is reflected, bearing information is also obtained.

Sonar equipment which depends primarily on a transmitted sound wave and the reception of an echo to determine range and bearing of a target is known as echo-ranging sonar. Another type of sonar is listening sonar. This type relies on the target as a sound source rather than transmitting a sound to be returned. Although most sonar can operate in either the active (echo-ranging) or passive (listening) mode, surface ships and aircraft generally use the active mode and submarines the passive.

In order to understand sonar you must possess an understanding of sound waves. Sound waves are similar to and are described in the same terms as radio waves; that is, sound waves have frequency, wavelength, and velocity.

The source of any sound wave is a vibrating mass. In echo-ranging sonar equipment the source of a sound wave is a transducer. (Transducers are explained later in this chapter.) Figure 15-1 shows the sound waves that are produced by a sonar transducer when it is suspended in water.

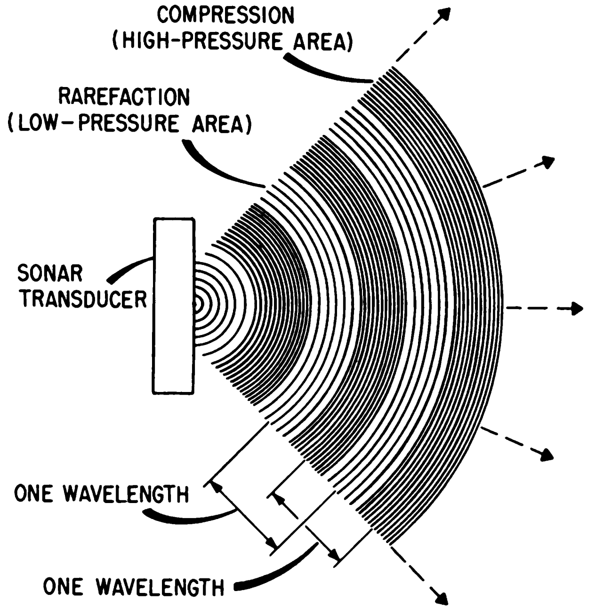


Figure 15-1.—Sound waves produced by a transducer.

When the diaphragm of the transducer moves outward, it moves the water next to the diaphragm. This produces a high pressure area or compression in the water. When the diaphragm of the transducer moves inward, the water next to the diaphragm moves inward. Thus, a low pressure area or rarefaction is produced. While the diaphragm is vibrating, alternate compressions and rarefactions travel outward from the transducer in the water. The distance between two successive rarefactions or two successive compressions is the wavelength of the sound wave. The frequency of the sound wave is the number of wavelengths that occur every second and is measured in cycles per second. Velocity of sound (in ft/sec) is the distance sound travels (in feet) per unit of time (a second) and is dependent upon several factors.

FACTORS AFFECTING THE SOUND BEAM

The particular sound waves of interest to sonar operators are the waves that leave the sonar transducer in the form of a beam and go out into the water in search of a submarine. If the sound beam finds a target, it will return in the form of an echo.

The use of sonar equipment depends on the presence and the recognition of an echo from a target. Detection of the echo depends on the quality and relative strength (loudness) of the echo compared to the strength and character of other sounds which tend to mask it.

It is important for sonar operators to know what things can weaken the sound beam as it travels through water, what factors in the sea water determine the path and speed of the sound beam, and what things affect the strength and character of the echo.

When the sound beam travels through water, it encounters hazards of travel which will weaken it or reduce its strength. Any signal strength lost in this manner is known as a transmission loss.

Absorption

Some of the sound is absorbed in passing through water. The amount of sound lost this way depends on the state of the sea. Absorption is high when winds are great enough to produce whitecaps and cause a concentration of bubbles in the surface layer of the water. Absorption is also much greater in wakes and strong currents, such as riptides. Echo ranging through wakes and riptides is therefore difficult, owing to the combined effects of false echoes, high reverberations, and increased absorption. Absorption is greater at high frequencies than at low frequencies.

Scattering

Sound waves are weakened when they reach a region of sea water that contains foreign matter, such as seaweed, silt, animal life, or air bubbles. This foreign matter scatters the sound beam and causes loss of sound energy. The practical result of scattering is to reduce echo strength, especially at long range.

Reflection

Echoes occur when sound strikes an object or a boundary in such a manner as to reflect the sound or to throw it back to its origin. You've probably stood in a tunnel and yelled, "Hello!" just to hear the echo of your voice. Your voice sent sound waves out through the medium of the air. When these waves reached an object of different density (the side of the tunnel), some of them were reflected back, and the echo was heard.

The same thing happens when sound strikes a metallic object like a submarine. Sound waves sent out by the sonar transducer hit the submarine, and some of the sound waves are reflected back as an echo. This echo is picked up by the transducer and delivered to your ears.

Reflection of sound waves sometimes occurs when a wave strikes a medium of different density from that through which it has been traveling. This will occur in cases where the two mediums are of sufficiently different densities and the wave strikes at a sufficiently large angle. This reflection is caused by the fact that mediums of different densities transmit sound at different speeds. For instance, a sound wave traveling through sea water is almost entirely reflected at the boundary between the water and the air. The speed of sound in sea water is about four times greater than that of sound in air, and the density of the water is more than 800 times greater than that of air. Therefore, practically all of the sound beam will be reflected downward from the sea surface.

Similarly, when a sound wave traveling through sea water strikes a solid object like a submarine, the difference in the density and sound velocity in the two mediums is such that all but a small part of the sound beam is reflected. That portion of the beam which strikes surfaces of the submarine perpendicular to the beam will be reflected directly as an echo. Refer to figure 15-2 for a pictorial explanation of this.

In a calm sea most of the sound energy that strikes the surface from below will be reflected back into the sea. A scattering effect occurs as the sea becomes progressively rougher. In these circumstances, part of any sound striking

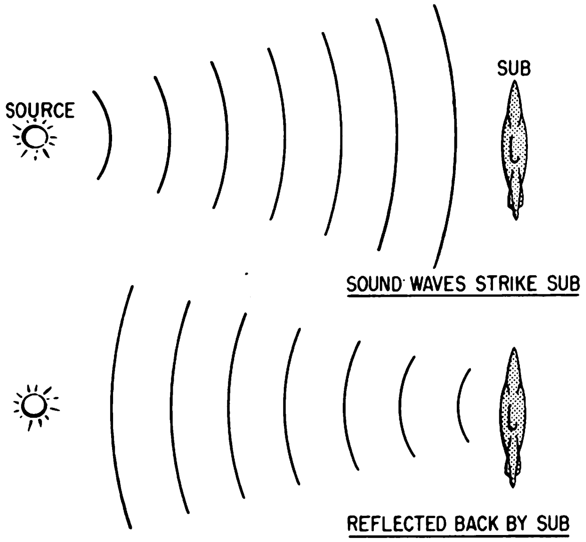


Figure 15-2.—Part of the sound comes back.

the surface is lost in the air and part is reflected in scattered directions in the sea. In water less than 600 feet deep, the sound may also be reflected from the bottom. Other factors being equal, the transmission loss will be least over a smooth sand bottom and greatest over soft mud. Over rough and rocky bottoms, the sound is scattered, resulting in strong bottom reverberations.

Reverberations

When sound echoes and re-echoes in a large hall, the sound reverberates. Reverberations are multiple reflections. Here is an example of this in nature: A discharge of lightning causes a quick sharp sound, but by the time the sound of the thunder is heard, it is usually drawn out into a prolonged roar by reverberation.

A similar case often arises in connection with sonar. Sound waves often strike small objects, such as fish or air bubbles, in the sea. These small objects cause the waves to scatter. Each object produces a small echo which may return to the transducer. The reflections of sound waves from the sea surface and the sea bottom also create echoes. The combined echoes from all these disturbances are called reverberations. Since they are reflected from various ranges, they seem to be a continuous sound which is stronger at first and gradually fades away. Reverberations from nearby points may be so loud that they interfere with the returning echo from a target.

Reverberation or backward scattering of the sound wave is of three main types.

There is a reverberation from the mass of water. Causes of this type of reverberation are not completely known, although fish and other "scatterers" contribute to it.

Another type is reverberation from the surface. This is most intense immediately after the transmission goes out, then it decreases rapidly. Intensity of the reverberation increases markedly with increased roughness of the sea surface.

There also is reverberation from the bottom. In shallow water, this type of reverberation is the most intense of the three, especially over rocky and rough bottoms.

Spreading or Divergence

Just as the beam from a searchlight spreads out and becomes weaker with distance, so also does sound. The farther the target is from the sonar transducer, the weaker the sound waves will be when they reach it. This is known as spreading or divergence.

Refraction

If there were no temperature differences in the sea, the sound beam would travel in a straight line, since the speed of sound would be roughly the same at all depths. As indicated in figure 15-3, the beam of sound would spread and become weakened by absorption at a relatively constant rate. At normal search speeds in deep water, with sonar equipment in good condition, and calm to moderate seas, the maximum echo range on a submarine would almost always lie between 2,000 and 4,000 yards, and would be independent of submarine depth.

Unfortunately, however, the speed of sound is not the same at all depths. The velocity of sound in sea water increases from 4,700 feet per second to 5,300 feet per second as the temperature increases from 30° to 85° F. Salinity and pressure effects on sound speed are usually not important compared to the large effects commonly produced by temperature changes in the sea. Because of the varying temperature differences in the sea, the sound beam does not travel in a straight line but follows curved paths. This results in bending, splitting, and distortion of the sound beam.

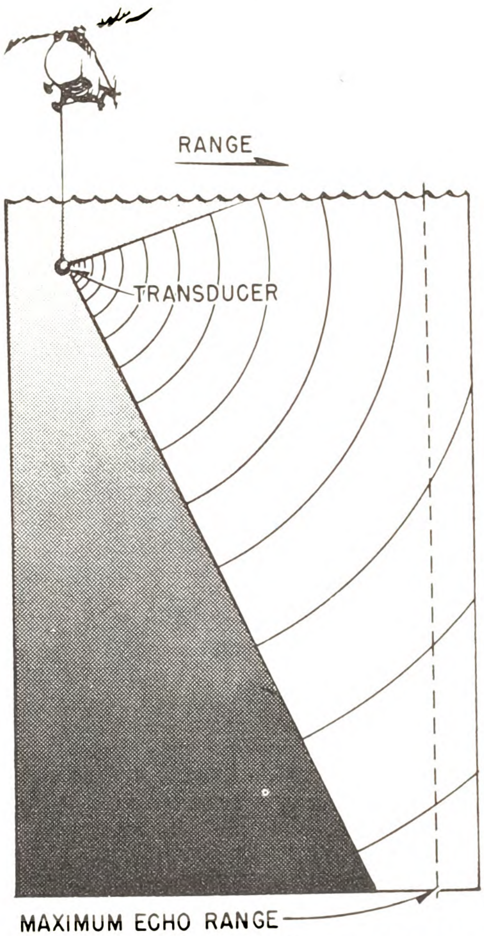


Figure 15-3.—The beam in water of constant temperature.

When the beam of sound is bent, it is said to be refracted. A sound beam is bent or refracted when it passes from one medium in which its speed is high (such as warm water) into one in which its speed is low (such as cool water). A sound beam will bend away from levels of high temperature and high sound velocity and toward levels of low temperature and low sound velocity. Figure 15-4 gives a better idea of this phenomenon called refraction.

As a result of refraction, the range at which a submarine can be detected by sound may be reduced to less than 1,000 yards, and this range may change sharply with changing submarine depth.

Speed of the Sound Beam

The three main characteristics of sea water that influence the speed with which the sound beam travels through the water are—

1. TEMPERATURE, which takes the form of slopes, or gradients.
2. PRESSURE, caused by increased depth.
3. SALINITY, or the amount of salt in the water.

Sea water has a high mineral content. The density of sea water is about 64 pounds per cubic foot while that of fresh water is about 62.4 pounds per cubic foot. This is the result of the salt content in the sea water. Salt content is spoken of as the salinity of the water.

The overall effect of increasing the salinity is to increase the speed of the sound. This means that when sound passes through water which varies in salinity, it travels faster in the saltier water. Such a change in salinity is considerable at the mouths of rivers emptying into the sea. Elsewhere the difference in salinity is too small to bother the rate of travel of the sound beam, and may be ignored.

Sound travels faster in water under pressure. The deeper sound goes in the sea, the higher the pressure on that water. Therefore,

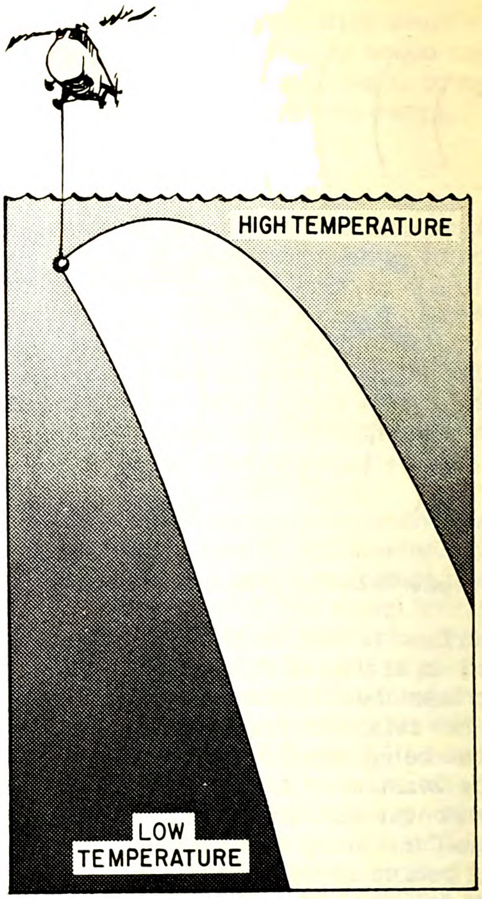


Figure 15-4.—Bending limits the range.

the speed of sound in the sea increases with depth. This effect is also rather small.

Temperature is by far the most important of the factors affecting the speed of sound in water. The speed of sound will increase with increasing temperature at the rate of 4 to 8 feet per second per degree change, depending on the temperature. Since the temperature of the sea varies from freezing in the polar seas to more than 85° F. in the tropics, and may decrease by more than 30° F. from the surface to a depth of 450 feet, it is clear that temperature is the most important factor. Remember: The speed of sound increases when the temperature of the water increases.

Depth and Temperature

Except at the mouths of great rivers where salinity may be a factor, the path followed by the sound beam will be determined by the pressure effect of depth and by temperature.

The pressure effect is always present and always acts in the same manner, tending to bend the sound beam upward. Figure 15-5 illustrates the situation when the temperature does not change with depth. Even though the temperature does not change, the speed of the sound increases with depth, due entirely to the effect of pressure, and the sound beam bends upward.

Figure 15-6 shows what happens when temperature increases steadily with depth. When the surface of the sea is cooler than layers beneath it, the temperature increases with depth, and the water has a positive thermal gradient. This is an unusual condition, but when it does happen it causes the sound beam to be refracted sharply upward.

When the sea grows cooler as the depth increases, the water is said to have a negative thermal gradient. Here the effect of temperature greatly outweighs the effect of depth, and the sound beam is refracted downward. This is illustrated in figure 15-7.

If the temperature is the same throughout the water, the temperature gradient is isothermal (constant temperature). Refer to figure 15-8. The surface layer of water is isothermal, but beneath this layer the temperature decreases with depth. This causes the sound beam to split and bend upward in the isothermal layer and downward below it.

Remember: When no temperature difference exists, the sound beam bends upward. When the temperature changes with depth, the sound beam bends away from the warmer water.

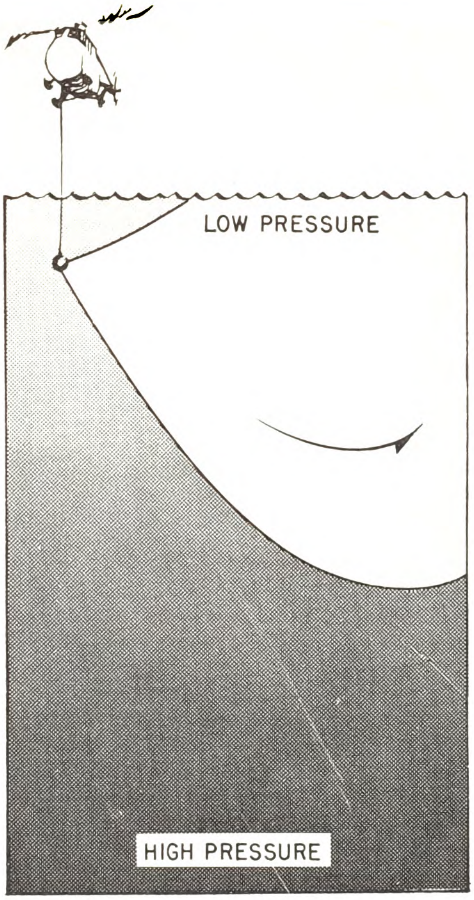


Figure 15-5.—Bending away from pressure.

Under ordinary conditions the sea has a temperature structure similar to that in figure 15-9. This temperature structure consists of three parts: First, a surface layer of varying thickness, with uniform temperature (isothermal) or a relatively slight temperature gradient; second, the thermocline, a region of relatively rapid decrease in temperature; and third, the rest of the ocean, with slowly decreasing temperature down to the bottom.

If this arrangement changes, the path of the sound beam through the water will change.

Layer depth is the depth from the surface to the top of a layer of sharp negative temperature gradient. Above layer depth, the temperature may be uniform, or a positive or weak negative gradient may be present.

Layer effect is the partial protection from echo-ranging and listening detection which a submarine gains when it submerges below layer depth. Some submarine commanders

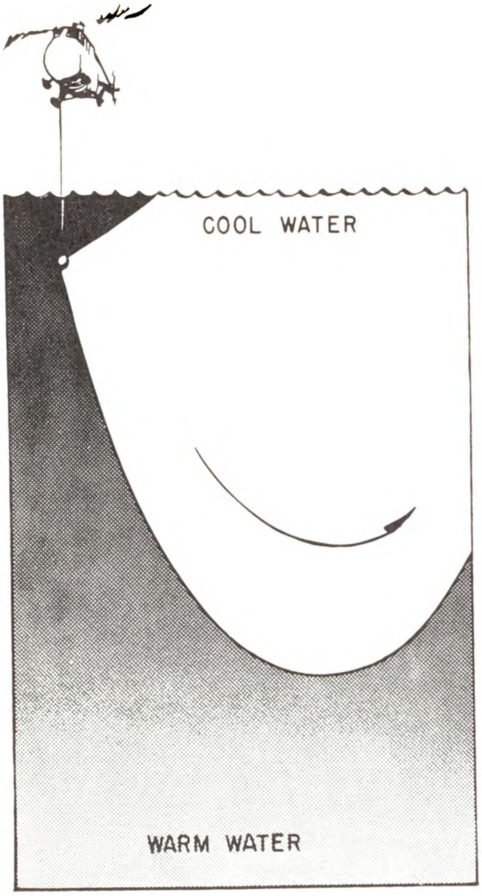


Figure 15-6.—Short ranges on a deep sub.

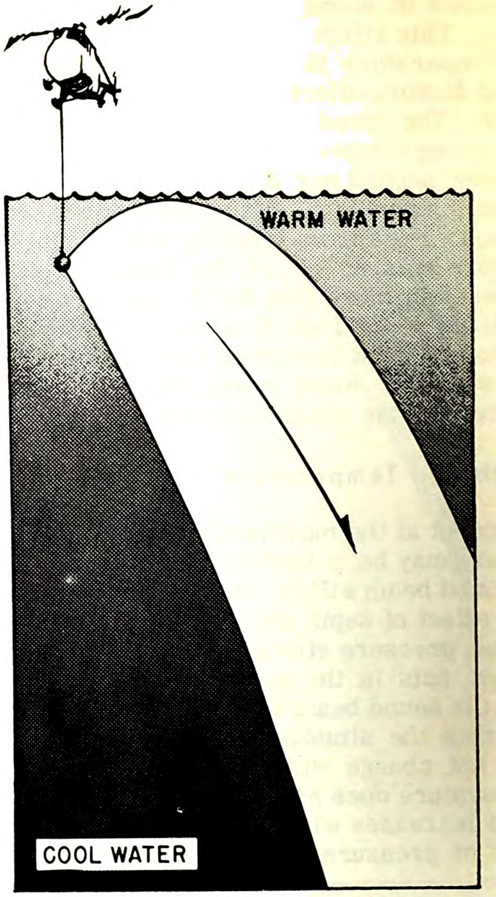


Figure 15-7.—Poor sound conditions.

have reported that, on diving through a sharp thermocline while taking evasive action, the screw noises of the enemy vessel were lost. Although the "pinging" could still be heard, the signal was of low intensity, and the enemy's tactics indicated that contact had been lost. Reports from surface vessels also indicate that ranges on submarines are greatly reduced when the submarine dives below a sharp thermocline, and that the echoes received are often weak and "mushy."

This partial protection afforded a submarine lying below a sharp thermocline is the "layer effect" just defined. Submarine commanders are aware of layer effect and make use of it in evasive tactics.

DOPPLER EFFECT

In order to thoroughly explain Doppler as applied to sonar, it will be necessary to do so from the shipboard approach. This is necessary because a full explanation of Doppler requires that 360° of azimuth be considered when sending out a signal and receiving an echo. Towed sonar as used by blimps and helicopters radiates and receives signals only from the forward direction, but shipboard sonar can be rotated 360°.

An important point to be learned from the following explanation is the fact that Doppler as applied to sonar operation differs from Doppler as applied to radar. In radar only two signal frequencies are considered—the transmitted signal frequency and the echo signal frequency. In sonar three signal frequencies are present—the transmitted signal frequency (the PING), the reverberation echo frequency, and the target echo frequency.

When actually attacking a submarine, one of the most important items of information the sonar operator can obtain is an accurate indication of Doppler. As the submarine changes its course and speed to escape depth charges or torpedoes, nothing will give away its escape tactics as quickly as Doppler.

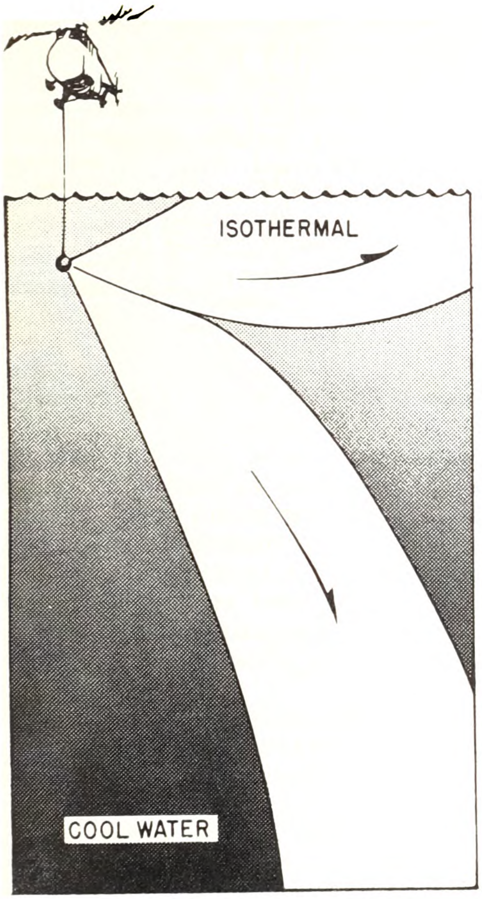


Figure 15-8.—Fair sound conditions.

You have heard Doppler many times, but probably did not know that it was called Doppler. For instance, when you were stopped at a railroad crossing and listened to the whistle of the engine as it approached, you will remember that the note of the whistle was HIGH as the train came near. As the train passed, the note or pitch of the whistle seemed to drop. And as the train went into the distance, the pitch of the whistle was LOW. That change in pitch was Doppler.

As the train approached, sound waves generated by the whistle were compressed and pushed ahead as they came near. These waves were heard as a high pitch because they were compressed. The shorter the distance between waves, the higher the pitch. When the train went on, sound waves from the whistle were drawn out. These waves were heard as a low pitch. Refer to figure 15-10 for an illustration of this.

Doppler works both ways. If you had been on that train instead of waiting at the crossing, and listened to the horn of the stopped car as you passed by, the pitch of the horn would be HIGH as you came toward it and LOW as you went away.

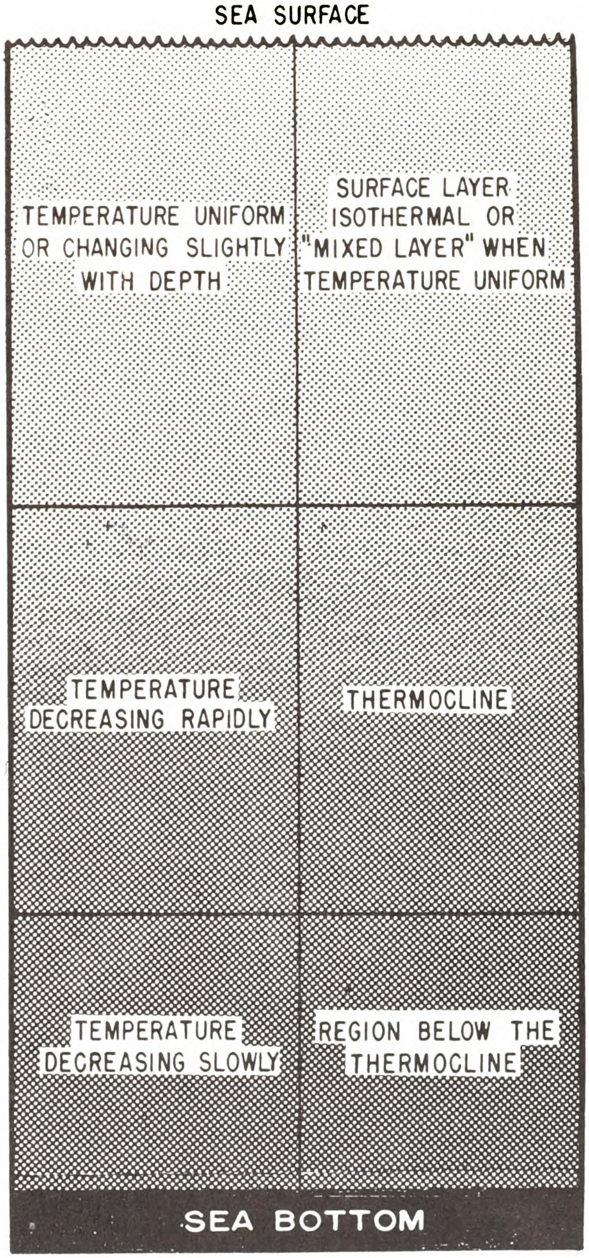

SEA SURFACE
TEMPERATURE UNIFORM OR CHANGING SLIGHTLY WITH DEPTH
SURFACE LAYER ISOTHERMAL OR "MIXED LAYER" WHEN TEMPERATURE UNIFORM
TEMPERATURE DECREASING RAPIDLY
THERMOCLINE
TEMPERATURE DECREASING SLOWLY
REGION BELOW THE THERMOCLINE
SEA BOTTOM

Figure 15-9.—Typical layers.

You probably are beginning to wonder what Doppler has to do with sound in the sea or with submarines. Sonar operators deal with three sounds. One is the sound actually sent into the water. The second is the sound of reverberations that echo back from all the particles in

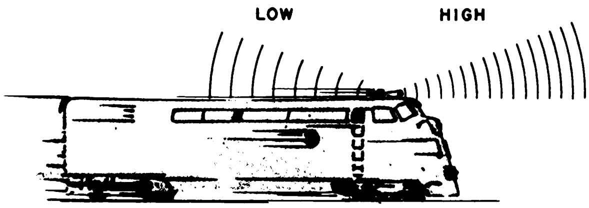


Figure 15-10.—Doppler.

the water—the seaweed, fish, and so forth. And then there is the most important sound of all—the sound of the echo from the submarine.

Forget about one of these sounds right now. That one is the sound sent into the water. Strangely enough, the actual PING is seldom heard. All but a few sonar equipments are designed so that the signal does not come out of the loudspeaker or headset. This means there actually are only two sounds to deal with in Doppler.

Reverberations are echoes from all the small particles in the water. Consider just one of these particles for a moment. A sound wave hits the particle and bounces back just as a ball would bounce back if thrown against a wall. If the particle is stationary, it will not change the pitch of the sound. The sound will return from the particle with the same pitch that it had when it went out.

Suppose you are on a DE and are stopped in the water. You send out a note of 20 kilocycles and the particles all send back a sound of the same pitch; that is, 20 kilocycles (20 kc. = 20,000 cycles per second).

Now suppose the ship gets underway and a ping is sent out dead ahead. It is just as if the ship were the oncoming train and the particles were sitting in the car listening to the approaching sound. Remember that as the train came forward, the pitch of the whistle sounded higher to the occupants of the car. In the same way, the particles "hear" a higher note and echo back a higher note. So, you, in the ship, will hear a higher note from the reverberations than the one sent out.

If the audio cursor is moved to dead astern, a lower note than the one sent out will be heard. Train the cursor on the beam, and the particles will echo back the SAME note sent out BECAUSE THE SHIP IS NEITHER GOING TOWARD THE PARTICLES NOR AWAY FROM THEM.

Look at figure 15-11 to see what happens when the ship is moving. Reverberations are highest when you train ahead and lowest when you train astern.

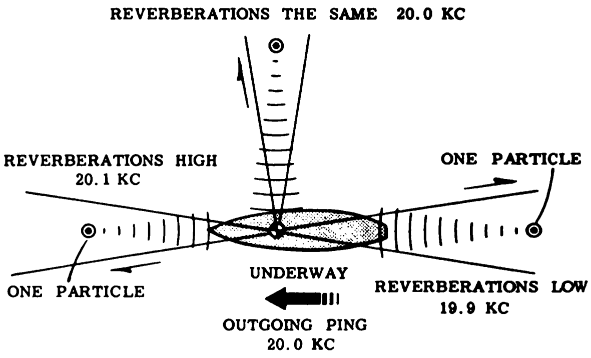


Figure 15-11.—Pitch is high ahead, low astern.

Consider the echo from the submarine. When the submarine is neither going toward nor away from the sound beam, it must be either stopped or crossing the sound beam at a right angle. If it is in this position, it reflects the same sound as the particles in the water. And the submarine echo is exactly the same pitch as the reverberations from these particles.

Whenever the pitch of the submarine echo and the pitch of the reverberations is the same, you know that the submarine is either stopped or that you are echoing off its beam. The submarine is neither coming toward nor away from the sound beam.

Figure 5-12 illustrates this. There is no difference in pitch between the echo from the submarine and the echo from the reverberation. Report NO DOPPLER.

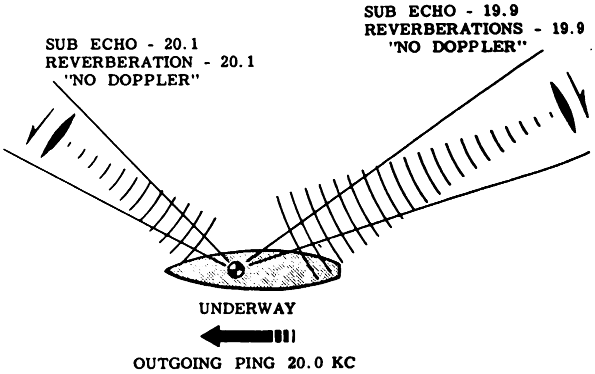


Figure 15-12.—You will hear no Doppler.

Now suppose that the submarine is coming toward the sound beam. It is as though the submarine were the train coming toward the car which was blowing its horn at the crossing. The horn sounded higher as the train approached the car, and the sound beam sounds higher to the submarine as it approaches the ship. So the submarine hears and reflects back a HIGHER echo than the particles in the water which are not moving. When the echo from the oncoming submarine is higher than the echoes from the reverberations, report DOPPLER HIGH.

When you report DOPPLER HIGH, you are telling the conning officer that the submarine is heading toward the ship. This form of Doppler is illustrated in figure 15-13.

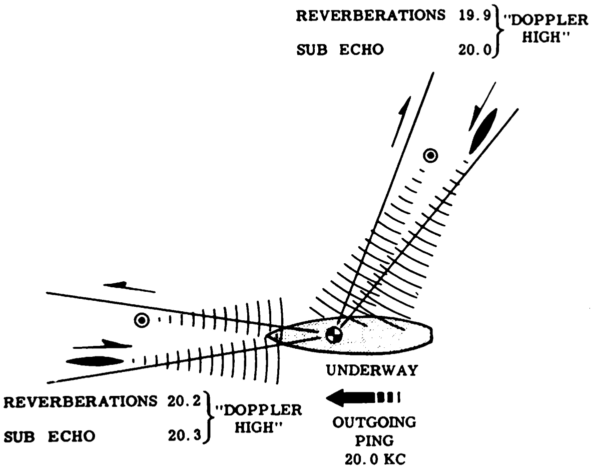


Figure 15-13.—Compare the echo and the reverberations.

The opposite form of Doppler will occur when the submarine is heading away from the ship. In this case, the echo from the submarine will be lower than the pitch of the reverberations.

Report it as DOPPLER LOW so that the conning officer will know the submarine is going away from the ship. This is illustrated in figure 15-14.

If you like definitions, you can say that Doppler is the difference in pitch between the reverberations and the submarine echo. When the echo is higher than the reverberations, you will sing out, "Doppler High!" If it is the same as the reverberations, report, "No Doppler." If the echo is lower than the reverberations, say "Doppler low."

When you become a really skilled operator, you will be able to give the degree of Doppler, that is, how high or how low it is. For instance, a submarine coming directly toward the ship at 6 knots would return a higher echo than a submarine coming directly toward the ship at 2 knots. Also, a submarine coming directly toward the ship at 6 knots will return a higher echo than a 6-knot submarine that is heading only slightly toward the ship.

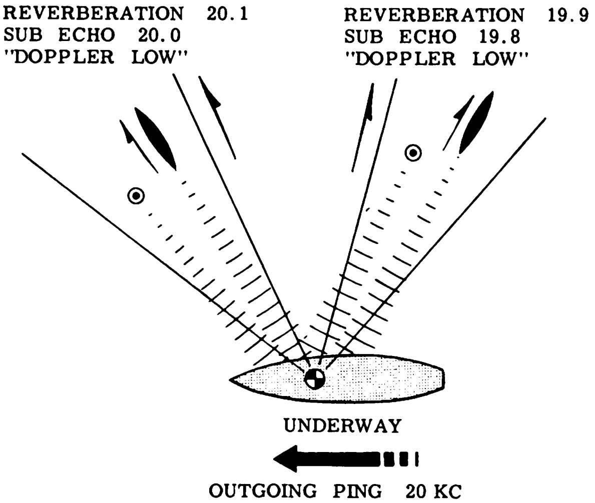


Figure 15-14.—You will hear DOPPLER LOW.

Two things count: how much speed the submarine is making, plus how much it is heading toward or away from the ship. The combination of these two is spoken of as the component of the submarine's speed toward or away from the ship. If the submarine's component is more than 6 knots, report DOPPLER HIGH (or LOW), MARKED. When it is 3 to 6 knots, inclusive, report DOPPLER HIGH (or LOW), MODERATE. If it is less than 3 knots, then call it DOPPLER HIGH (or LOW), SLIGHT. (See fig. 15-15.)

You can see now how very important it is to give an accurate report of Doppler to the conning officer. It tells conn whether the submarine is coming toward or going away from the ship and gives the component of the submarine's motion.

Doppler is also important to YOU, especially when making first contact and during the attack. Doppler enables you to tell the difference between a wake echo and a submarine echo. A wake echo is from a stationary object and can never have Doppler. But anything that does have Doppler is moving in the water; and if it is not a surface ship, it must be either a submarine or a large fish. Figure 15-16 gives an idea of the value of Doppler.

The submarine's wake has no Doppler but the submarine DOES have Doppler. If you couldn't hear Doppler, the echo from the wake would sound so much like the echo from the submarine that you could not tell them apart. To BE AN EFFICIENT OPERATOR, YOU MUST BE ABLE TO HEAR AND REPORT DOPPLER ACCURATELY.

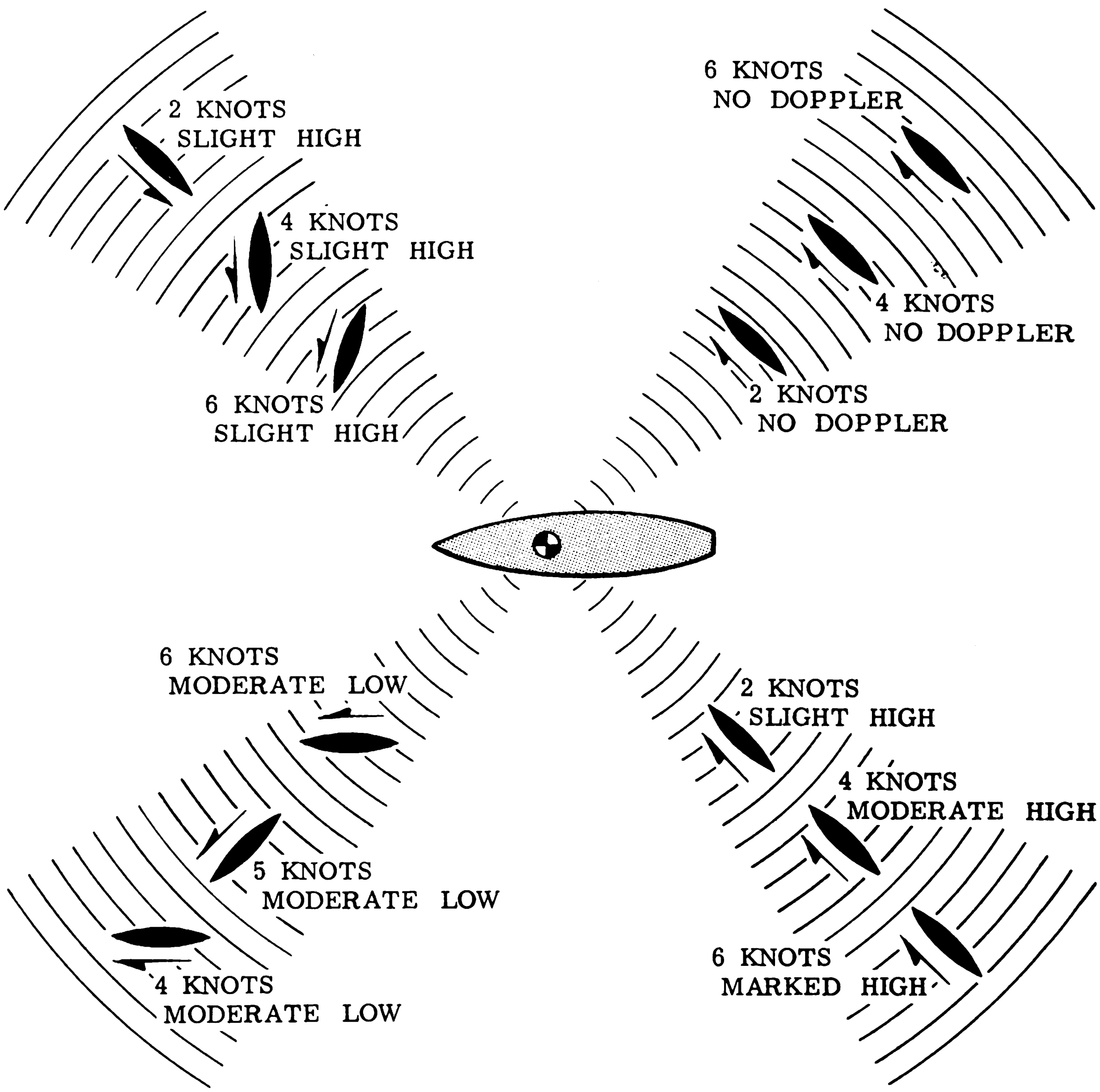


Figure 15-15.—Doppler gives component, toward or away.

TRANSDUCER

The sonar transducer is a watertight transceiver. The transducer is used to convert electrical energy into sound energy and sound energy into electrical energy. The transducer functions like the loudspeaker in an office intercom box, alternately converting electrical energy to mechanical motion and converting mechanical motion to electrical energy. Thus the transducer is an underwater loudspeaker during transmission and an underwater microphone during reception.

Transducers used in sonar operate on either the magnetostriction or the piezoelectric principle.

Magnetostriction Principle

The property that causes certain metals to shrink or contract when placed in a magnetic field is called magnetostriction. The stronger the magnetic field the greater the contraction. Magnetostriction is most pronounced in nickel and nickel alloys. For this reason nickel tubes are used extensively in magnetostriction transducers.

Transducers are similar to radio loudspeakers. A loudspeaker has a diaphragm that is caused to vibrate. These vibrations produce sound waves.

A transducer also has a diaphragm. Since this diaphragm is operated under the surface

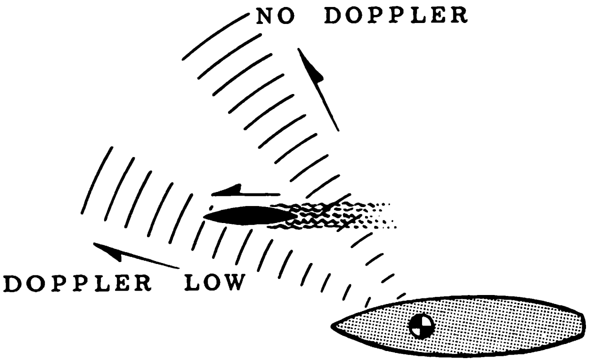


Figure 15-16.—You must hear the Doppler.

of the water, it must be much heavier in construction than a diaphragm operating in air. Therefore, it needs a large driving power. Nickel tubes, rigidly attached to a heavy diaphragm are placed in an alternating magnetic field. This alternating field causes the nickel tubes to contract and expand, which causes the diaphragm to vibrate and produce sound waves in the water. (See fig. 15-1.) The frequency of the sound waves depends upon the frequency of the alternating magnetic field around the nickel tubes.

The directivity of the transducer determines the accuracy of the bearing information. The sound beam for a given frequency can be made narrower in azimuth by increasing the width of the transducer diaphragm. If a higher operating frequency is used, the transducer can be made smaller and still have the desired directivity. However, there are limitations. If the frequency is increased too much, propagation losses caused by absorption become objectionable.

Piezoelectric Principle

Piezoelectric transducers operate in the same manner as the magnetostriction types except that crystals are used instead of nickel tubes. If a mechanical stress is applied to certain crystalline substances an electrostatic voltage is produced. Conversely, an electric field applied to a crystalline substance will cause a mechanical stress (expansion or contraction of the crystal). This property of crystals is called piezoelectricity. There are various types of crystals, such as quartz, Rochelle salt, tourmaline, and ceramic. For sonar, quartz crystals are not used because their frequency response is too narrow.

Rochelle salt and ceramic type crystals are often used in sonar transducers for two reasons. First, they have a broad frequency response and can be worked at frequencies far removed from their natural mechanical frequency. Secondly, Rochelle salts and ceramic material have a much greater piezoelectric activity than quartz. Crystals can be damaged by either moisture or high temperature. Since high power produces high temperatures, crystal transducers have a disadvantage in that they cannot handle as much power as a magnetostriction transducer. The advantages of crystal transducers are that they operate over a much wider frequency range than magnetostriction transducers and they are very efficient.

Typical Construction of Transducer

Figure 15-17 shows the construction of two transducers. The one shown in part (A) is a magnetostriction transducer which has many nickel tubes on the diaphragm. Part (B) shows the piezoelectric transducer which has many crystals. The nickel tubes of the magnetostriction transducer and the crystals of the piezoelectric transducer are placed so close together that they cause the backing plate to act as one huge vibrating surface. This arrangement is a contributing factor in producing the sound energy needed for sonar operation.

The magnetostriction transducer can be filled with a moisture-free gas to insure long trouble-free operation. The piezoelectric transducer uses a watertight case which has a rubber dome for the diaphragm. The case is filled with a special moisture-free oil. This oil, which has nearly the same sound transmission characteristics as sea water, acts as a medium between the crystal's vibrations and the diaphragm. Both types of transducers must be made watertight to prevent corrosive action.

HYDROPHONES

A hydrophone is an underwater sound detector (receiver). It is used only as a receiving device whereas a transducer is used for both transmitting and receiving sound waves. (The transducer acts as a hydrophone when it is receiving an underwater signal.) Hydrophones are characterized by the fact that they are highly directional. This enables them to provide accurate target bearing information. Also, they operate over a wide frequency range.

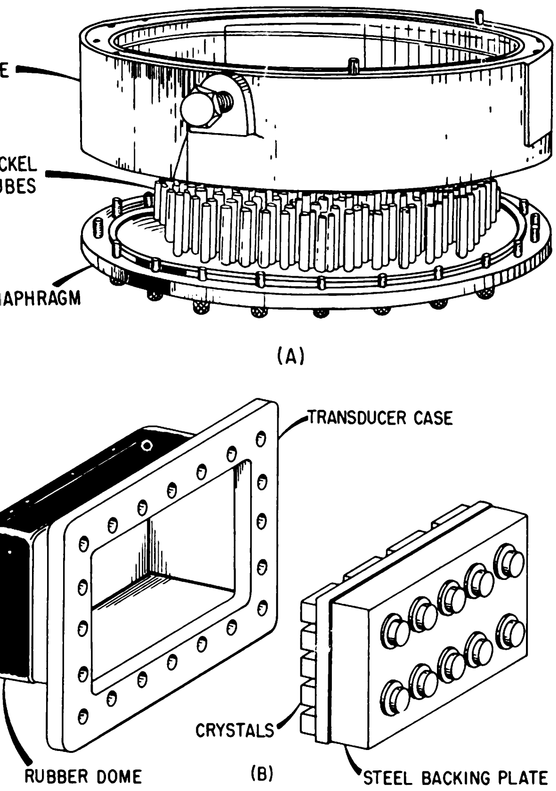


Figure 15-17.—Typical construction of transducers.

SONAR SYSTEMS

The major difference between radar and
nar is that radar transmits high speed
36,000 miles per second) radio waves in air
d sonar transmits relatively low speed
800 feet per second at 32° F.) sound waves
water. The travel time of the sound wave
om the transducer to the target and return
ay amount to several seconds. This time
pends on the range of the target and, to a
sser extent, on the several factors mentioned
rlier.

Several pulses of energy must strike each
get, whether working with sonar or radar,
insure that the target will be detected. Since
arch radars transmit several hundred pulses
r second, the radar antenna can be rotated
relatively high speeds during automatic
arch operations. This is not true with sonar.
actual sonar operation, it takes approxi-
ately four target echoes to definitely es-
lish the presence of a target.

pical Sonar

A block diagram of a typical sonar set is
own in figure 15-18. There are two methods
of operation—manual and automatic. When manual operation is used, the transducer is rotated manually to a certain sector and that sector is searched for targets. When automatic operation is used, the transducer is automatically rotated in steps to complete a revolution. Usually, this system can also be used to listen as well as to echo range.

The alternating signal produced by the oscillator in the transmitter can be any frequency from subsonic (below 20 c.p.s.) through ultrasonic (above 20,000 c.p.s.). The operating frequency is mainly determined by the range or the bearing accuracy desired. (Remember, as already stated, that the higher the frequency the more accurate the bearing information because the sound beam is narrower, but the sound beam energy travels a shorter distance. Also, the lower the frequency the greater the range but the less accurate the bearing.) The signal produced by the oscillator is amplified through several power amplifiers so that it is strong enough to effectively operate the transducer. The transducer may be either the piezoelectric or the magnetostriction type.

The training mechanism is a servo system that controls the direction of the transducer and supplies a signal to the bearing indicator. The bearing indicator, since it relates the direction the transducer is facing, indicates the direction of the target when an echo is received.

Return echoes received by the transducer are applied to the receiver section of the sonar set. After a stage of preamplification, the signal is converted to an intermediate frequency by the mixer stage. This IF signal is amplified and fed to a detector stage. From the detector stage an audio signal is made available. Headphones, meters, cathode-ray tubes, tape or wire recorders, and paper recorders can be used to collect and record received information.

The temperature of the water at different depths should be known so that more accurate sound velocities can be determined. Sensitive recording devices are used to collect this information. One type of recorder utilizes a sensitive thermistor. The temperature change of the water changes the resistance of the temperature sensitive thermistor and this resistance change is converted to a temperature reading.

Two major problems that are common to airborne sonar operations are (1) getting the transducer in the water and (2) the speed at

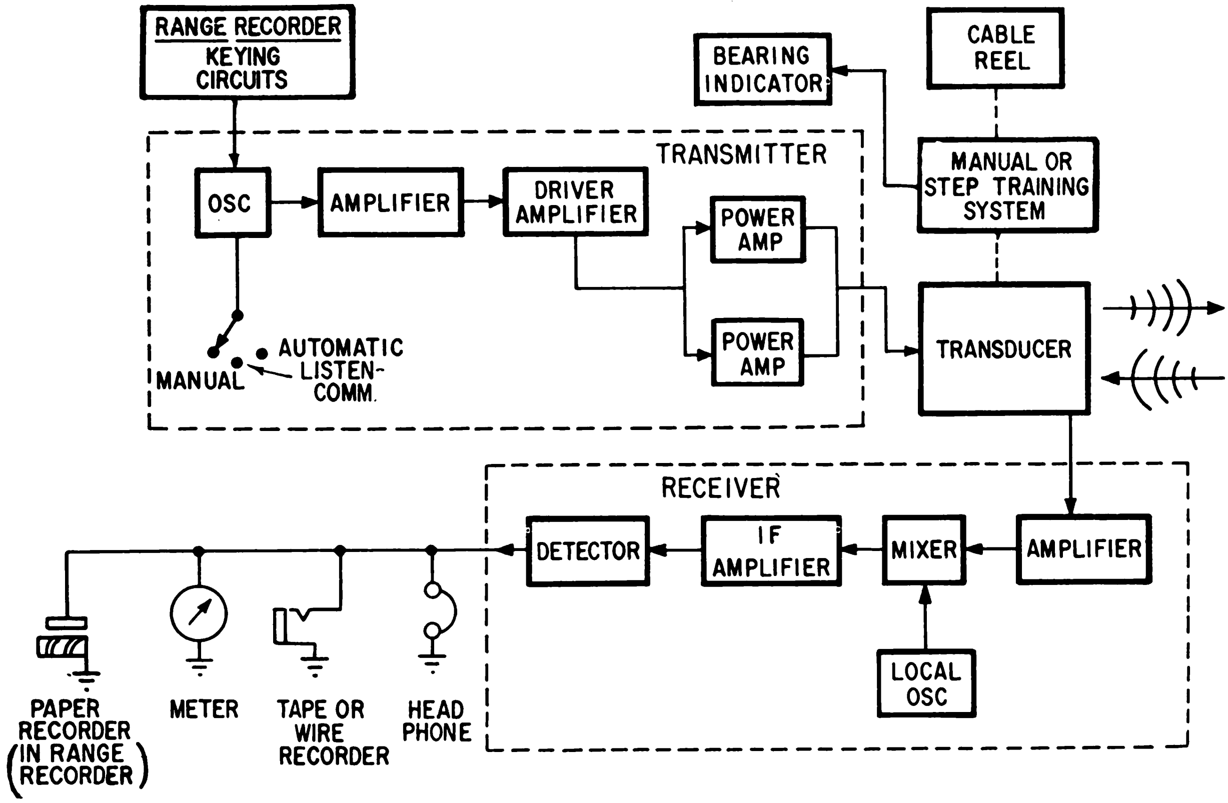


Figure 15-18.—Block diagram of typical sonar set.

which the transducer is towed. Any object being towed rapidly through water builds up turbulence. Therefore, sonar operation is practical only from slow moving craft, such as helicopters and blimps. If the transducer is moved too rapidly the turbulence created around it will mask out all other sounds.

One method of getting the transducer in the water utilizes a cable and reel. (See fig. 15-19.) Helicopters using this type cable and reel can hover over an area and dip the transducer to the desired depth. Therefore, the name "dipping sonar" is used in conjunction with this type cable and reel.

Another type sonar is called "towed sonar." Here, the transducer is housed in a streamlined, bomb-shaped body, as shown in figure 15-20. This winged body is streamlined for water travel so that it can be towed at speeds up to 50 knots without excessive turbulence. This streamlined body is heavy and is towed by blimps rather than helicopters. The cable used to raise and lower either the dipping or the towed sonar also serves to conduct the electrical signals to and from the transducer. The bomb-shaped housing, shown in figure 15-20, contains devices for measuring the water temperature and the speed of the body through the water, and also for indicating its depth in the water.

Besides rapid coverage of vast areas, airborne sonar has several other advantages over shipboard sonar. Airborne sonar requires that only the transducer be placed in the water, making it virtually invulnerable to submarine torpedo attack. The airborne sonar transducer is not subject to the aircraft's engine or propeller noises. Additional advantages are ease of operation and economy of cost.

Sonar Set AN/AQS-4A

This is an airborne dipping sonar set which provides the means of detecting waterborne targets from a hovering aircraft. The set serves two primary tactical purposes—(1) it provides the means of setting up a sonar barrier around a fleet or convoy, and (2) it facilitates the rapid sonar search of a large area.

Detection is accomplished by lowering a transducer into the water to the desired depth for searching operation. Two types of echo-ranging operation are provided—continuous

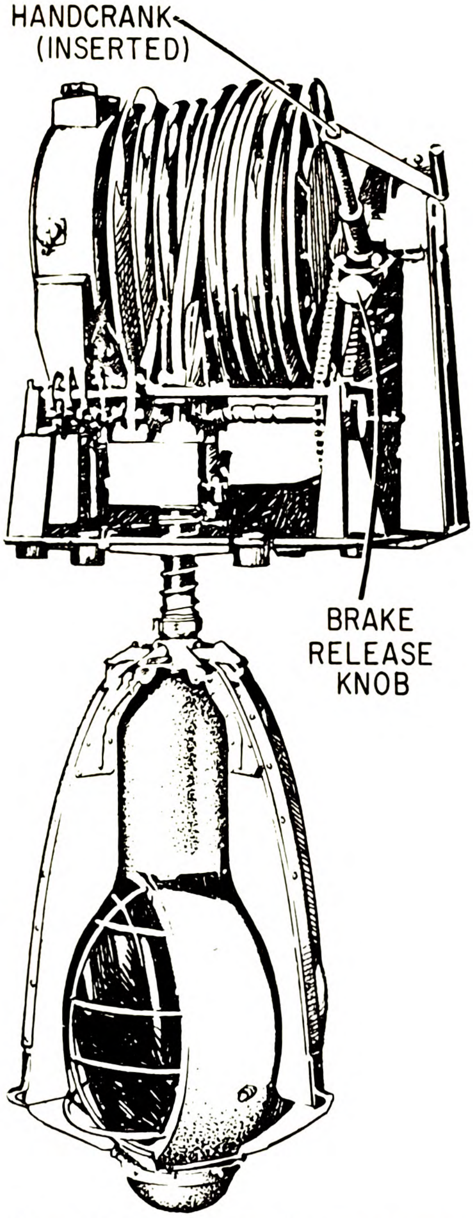


Figure 15-19.—Transducer for dipping sonar.

manual-training and automatic step-training. Also, facilitates for ultrasonic listening are provided.

Communication between sonar units that are installed in different aircraft, ships, or submarines is accomplished by use of a key similar to that used in radio CW communication. For example, two helicopters using dipping sonar may communicate with each other by Morse code sent out as sound waves from their respective sonar transducer.

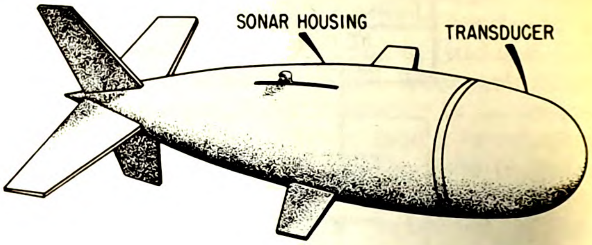


Figure 15-20.—Transducer housing for towed sonar.

Figure 15-18, which has already been referenced, is a functional block diagram of a typical sonar system such as the AQS-4A. For security reasons, actual operating frequencies and maximum capabilities are omitted; however, these omissions do not detract from the overall explanation of the operation of the set.

In echo-ranging operation, a pulsed CW signal of adjustable duration is transmitted by the sonar transducer. The Range Recorder (fig. 15-18) provides selection of ranges of operation and pulse width, thereby controlling the pulse transmitted by the transducer. The selected CW signal is generated by the oscillator, amplified to a high power level, and directed to the transducer where it is emitted as a sound wave.

As previously mentioned, the transducer can be trained either automatically or manually. In automatic operation the bearing of the transducer is increased in 10-degree steps prior to each transmitted pulse. Consequently, the area may be methodically searched in the time required to transmit 36 pulses. This length of time will depend on the range selected.

In manual operation the transducer may be trained by a handwheel located on the Azimuth Indicator. In the manual mode of operation a selected bearing or selector can be intensively searched.

The transmitter, as explained in connection with figure 15-18, supplies the high powered signal to the transducer. Figure 15-21 shows the Transmitter/Receiver unit of the AQS-4A.

The sonar receiver is a fixed-tuned, highly selective superheterodyne circuit. It contains an ultrasonic amplifier, a converter, one IF amplifier, and a diode detector. Also included, but not shown on the block diagram, are a beat-frequency oscillator and two stages of audio amplification. The receiver output is applied simultaneously to both visual and audible indicators; the visual indications are read from a Sonar Level Meter and the Range Recorder,

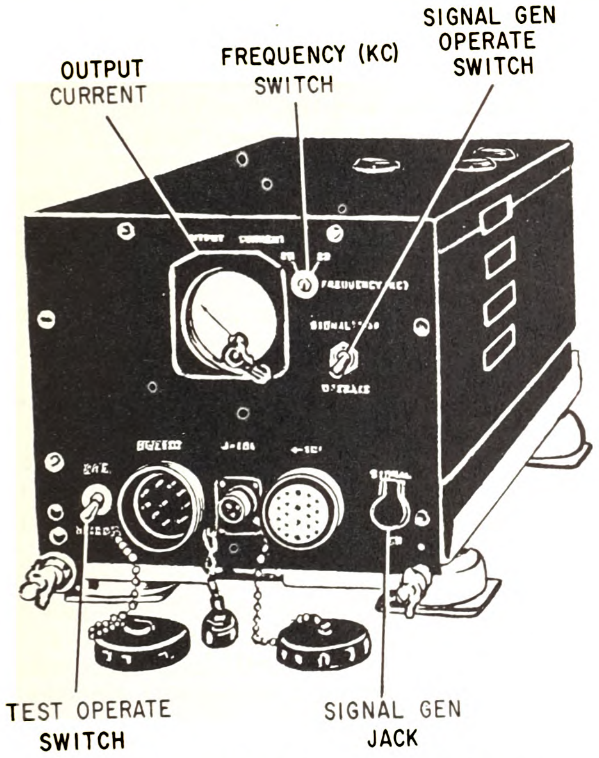


Figure 15-21.–AQS-4A, Transmitter/Receiver.

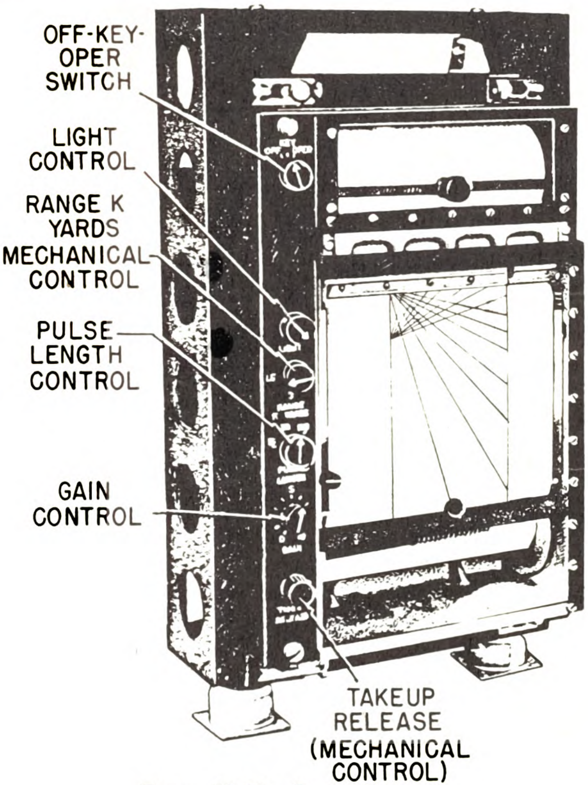

OFF-KEY-OPER SWITCH
LIGHT CONTROL
RANGE K YARDS MECHANICAL CONTROL
PULSE LENGTH CONTROL
GAIN CONTROL
TAKEUP RELEASE (MECHANICAL CONTROL)

Figure 15-22.—Range Recorder.

and the audible indications are fed to headphones and a wire recorder. The Level Meter continuously indicates in db the amplitude of received signals.

Output signals from the receiver are further amplified in the Range Recorder (fig. 15-22) and applied to the writing instrument. The echo signals therefore cause a permanent impression to be made on the chemically treated recording paper. The writing instrument is synchronized with the starting point of the repetition rate cycle. The distance of the recorded echo mark from the transmitted pulse mark indicates the range of the target. The recorder has an engraved range-in-yards scale that facilitates accurate determination of target range. When a number of echo signals have been received and recorded, the range rate (opening or closing range) can also be determined.

Training orders are the voltages applied to a training motor that trains the transducer in a desired direction. In automatic step-training the orders originate in the Range Recorder and train the transducer in steps. The training motor is located on the Sonar Dome, the spherical dome above the transducer.

Training is accomplished by a servomechanism having a synchro control transformer as the error-measuring device, a servo amplifier, a training motor, and a flux-valve compass as the transducer positioning transmitter. Training orders are introduced to the control transformer by means of the training handwheel or the step-training mechanism. At the same time, transducer position information voltage is supplied to the control transformer by the flux-valve compass. If any difference exists between the ordered and actual bearing of the transducer, an a-c bearing error signal appears at the output of the control transformer. This error signal is converted to an error voltage which is used to rotate the transducer to the ordered bearing. A compass dial bearing indicator, mechanically linked to the control transformer, indicates the ordered bearing of the transducer. A flux-valve compass, with provision for variation corrections, indicates the true bearing position of the transducer.

A combined height-depth indication circuit provides accurate determination of helicopter height and Sonar Dome depth during operation. Either helicopter height or signal cable length indications are provided to the pilot on the Drift-Height Indicator. (See fig. 15-23.) Dome depth indications appear on the Depth Meter on the Azimuth Indicator.

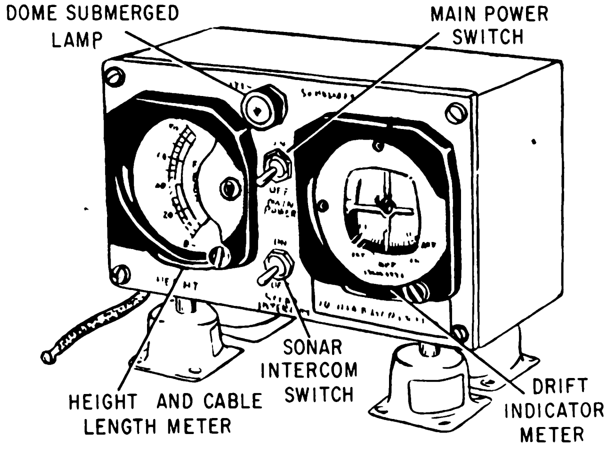


Figure 15-23.—Drift-Height Indicator.

An ohmmeter circuit is employed to provide the height and depth indications. Two potentiometers are used—one to count the turns of the reel as the dome is lowered and one that is pressure operated and mounted behind the transducer. Thus, when the dome is lowered from its seated position to the operating position the potentiometers indicate the helicopter's height (or cable length) and the depth.

Two "dome-submerged" lamps indicate the time of dome submergence. When the dome enters the water, the lights light automatically and the time of submergence can be noted.

Drift of the dome and helicopter is measured by a cross-fork arrangement mounted on the hoist. Relative drift must be known to the pilot in order that he may cause the helicopter to hover directly over the dome. Drift up to 20-degrees forward-aft and 20-degrees port-starboard is presented to the pilot by means of two cross-pointers on the Drift-Indicator Meter on the Drift-Height Indicator.

Aircraft drifts are determined by measuring the deviation of the signal cable from the line normal to the surface of the water at the position of the sonar dome. This is accomplished by passing the signal cable through two crossed forks, mounted horizontally at a 90-degree angle to the hoist. Each fork is pivoted on the movable arm of a potentiometer. Any vertical deviation of the cable moves one or both potentiometer arms, thereby providing the required drift indication signals.

Most of the operating controls of the AQS-4A are located on the Azimuth Indicator. This unit provides several features not previously mentioned. As can be seen in figure 15-24, provision is made to connect the sonar equipment to the helicopter's ICS or VHF system. To maintain high sonar operational efficiency, the audio switching circuits are designed so that the pilot can communicate with the sonar operator without the operator having to change any controls. A momentary-contact switch operated by the pilot connects the sonar operator's headphones into the ICS system. Sonar operation is interrupted in the operator's headphones during this time.

Should the sonar dome develop leakage while in the water the leakage light on the Azimuth Indicator will automatically have voltage applied across it.

The hand key mounted on the side of the Azimuth Indicator may be used for communication between sonar sets by selecting the LISTEN-COMM position with the sonar switch. When this operation is selected, the power to the transducer is reduced to one-half to prevent damage when the key is depressed for long periods of time. The Azimuth Indicator is equipped with jacks for connecting a microphone, a headphone, and a wire recorder. It also contains calibrations controls and the indicating meters and dials mentioned earlier.

Sonar Set AN/AQS-2

This sonar set is a type of towed sonar and is similar in many respects to the AN/AQS-4A which has just been discussed; however in some respects it differs. The AQS-2 is a system that is designed to detect underwater targets, such as submarines, from a lighter-than-air type aircraft.

The transducer is contained in a streamlined waterborne unit (Transducer Group) which is towed through the water by the aircraft (blimp). It may be submerged to a depth of 300 feet and towed at speeds up to 50 knots at that depth. The Transducer Group (fig. 15-20) is towed by a combination strain and electrical cable. This cable is the connecting link between the Transducer Group and the equipment in the aircraft. A winch in the aircraft lowers and raises the Transducer Group, and controls the towing depth.

The AQS-2 system is a search-type sonar which searches an area that lies within 180 degrees of azimuth ahead of the Transducer

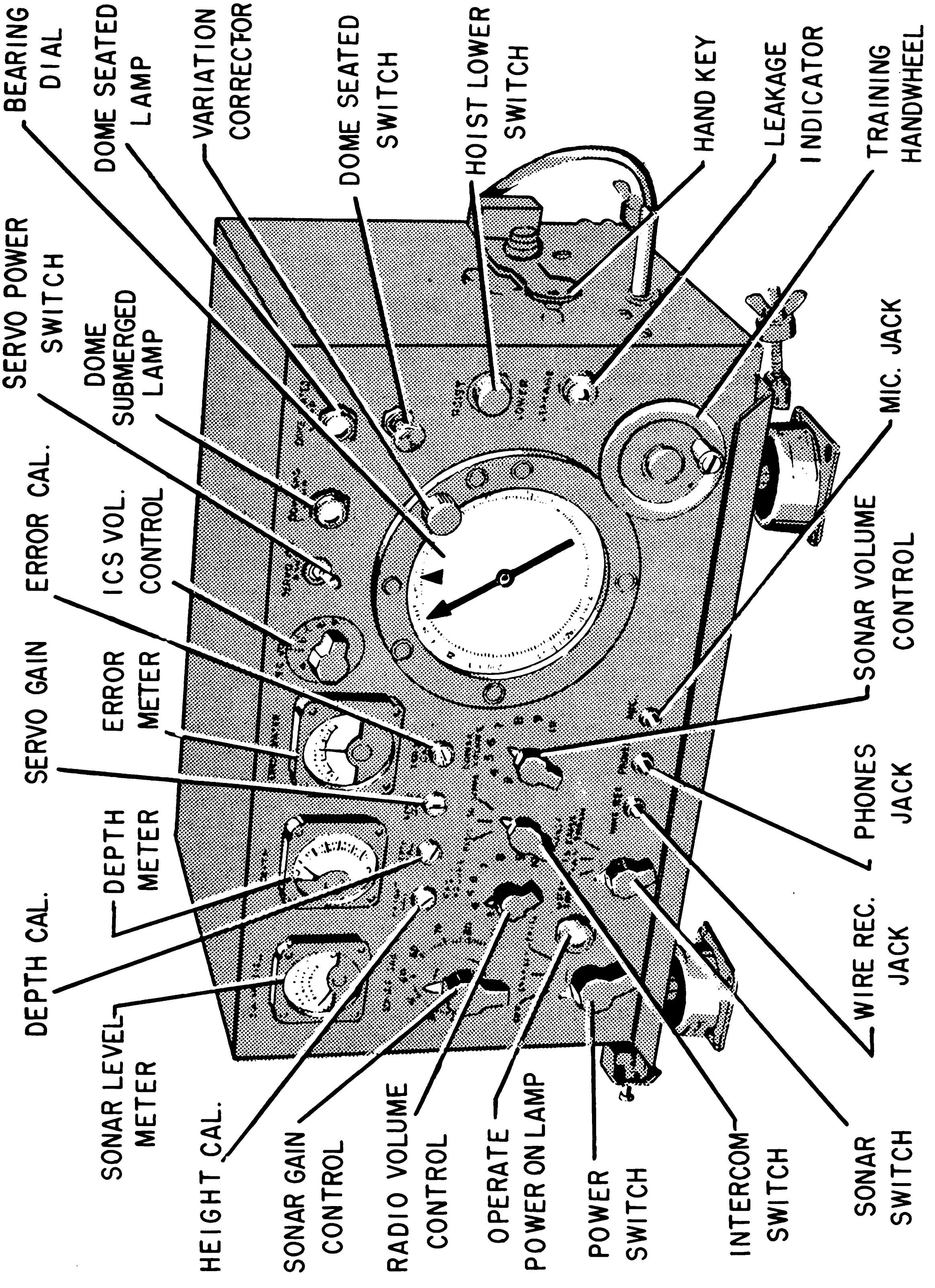


Figure 15-24.—Azimuth Indicator.

Group. This search is done during each transmission of a ranging sound pulse. The receiving circuitry of the transducer is arranged so that echoes (or target noises when listening during passive operation) are received over twelve highly directional paths (beams). This arrangement enables target bearing to be determined. The sonar set can also be used for CW communication with other units that are using sonar of the same frequency.

The major units of the AQS-2 are the Transducer Group, Control-Indicator, Amplifier Control, Sonar Transmitter, Power Supply, D-C Amplifier, Recorder, and Course, Depth, and Speed Indicators.

The Transducer Group contains the transducer and related electronic equipment. The transducer, which is located in the nose section of the housing, is a crystal type. It is constructed so that the transmitting array effectively covers about 180 degrees of azimuth, or up to 90 degrees either side of center. The sound pulse is transmitted over this broad angle in order that the number of targets intercepted by the pulse may be greatly increased. A unique feature of this transducer is that immediately after the transmission of the broad-angle pulse the characteristics of the transducer are changed. During the period of reception, it becomes responsive to returning echoes in one or more of twelve receiving beams which are highly directional in azimuth.

The transmitting condition may be compared to half a disk wheel where the hub portion represents the transducer, and the disk portion represents the field of sound emanating from the transducer. The receiving condition is roughly compared to half a spoked wheel where the hub portion represents the transducer, and the spokes represent the receiving beams. With proper amplification for each receiving beam, and with rapid commutation and suitably shaped and timed sweeps, the echoes may be shown as targets on a PPI display. It is in this manner that many targets within range can be revealed simultaneously over a considerable angle of azimuth.

The electronic equipment installed within the transducer group consists of:

1. Amplifiers to raise the received noise signals or echoes to a level high enough for transmission through the towing cable to the aircraft where they can be further amplified.
2. A network for shaping the receiving characteristics of the transducer into 12 adjacent beams, each 15 degrees wide, in the forward looking 180 degrees listening angle of the transducer.
3. Control, switching, protective, and tuning circuits.
4. A power supply.
5. Temperature, speed, depth, and compass elements for supplying related information to the operator in the aircraft.

The purposes of the Control-Indicator, which is located in the aircraft, are to control operation of all other components of the system, provide a visual display showing the range in yards and the true bearing of a detected submarine relative to the transducer, and to provide headphone listening facilities for target noises or echoes. The unit also has provision for a hand telegraph key for underwater communication. Figure 15-25 shows the Control-Indicator.

Sonar Maintenance

Before attempting to locate and correct trouble in a sonar system refer to the HSI. These instructions discuss the operation and maintenance of the set and also set forth common troubles and give procedures to be followed in locating them. A sonar system requires certain test equipments that are to be used for making tests and adjustments. These test equipments vary from system to system; however in most respects they are similar.

A typical test set provides a means for performing bench tests and preflight tests. The test equipment must provide signals to the sonar set and it must function as a receiving equipment to give indications of the sonar system output. Signals must also be provided for purposes of calibrating the various oscillators of the system. Remember, always consult the HSI to insure that correct procedures will be followed.

Sonobuoys

GENERAL DESCRIPTION

The listening sonobuoy is an expendable equipment, designed to be dropped from carrier type and patrol type aircraft. The purpose of this sonobuoy is to detect underwater sounds and to transmit these sounds to nearby aircraft or ships. Figure 15-26 shows a complete

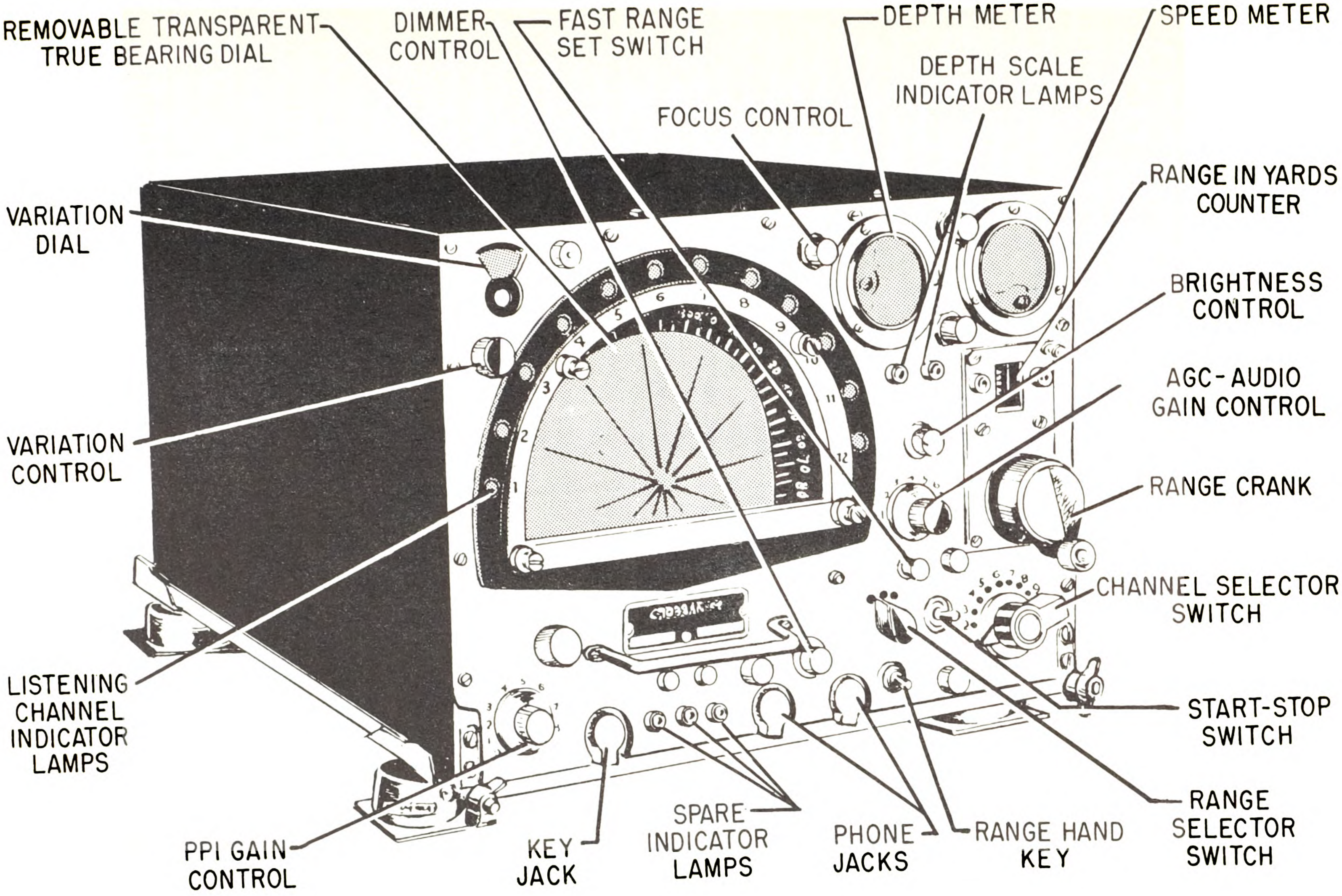


Figure 15-25.—Control-Indicator.

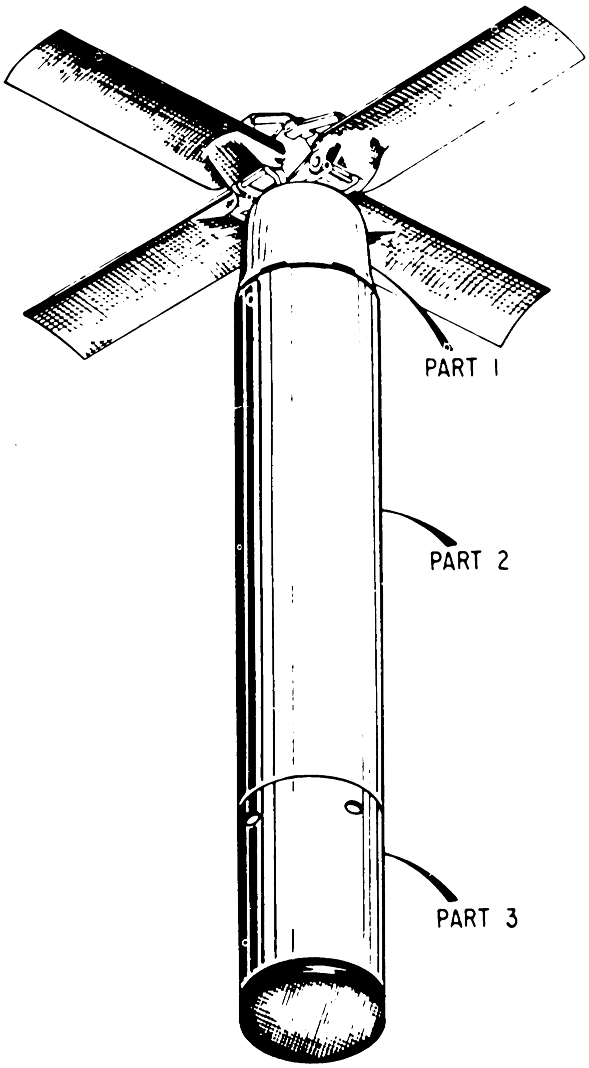


Figure 15-26.—Listening sonobuoy.

receiver-transmitter combination designed to float in an upright position in the water.

A surfaced submarine can readily be detected by airborne radar at great distances. However, it is difficult for the aircraft to get within striking range of the submarine without being detected because the submarine is also equipped with search radar. The submarine will immediately dive when an enemy aircraft is detected. The aircraft will arrive in the general vicinity of the submerged submarine a few minutes later and will drop listening sonobuoys in an effort to relocate the submarine.

Upon being dropped from an aircraft, four blades on the cap of the sonobuoy open. (See part 1 of fig. 15-26.) These blades rotate because of the passage of air across their surfaces. This rotation produces two effects: (1) it stabilizes the sonobuoy so that it falls with the hydrophone down; and (2) it slows the rate of descent of the sonobuoy. The force that is produced when the sonobuoy hits the water causes several events. The rotating cap, since it is no longer needed, is ejected. When the cap is ejected, an FM transmitting antenna is permitted to erect itself. The impact causes two dye marker containers, located at the bottom of the sonobuoy (part 3 of fig. 15-26), to be broken, and also causes a hydrophone to be released. The hydrophone, which is a listening device, is connected to one end of a 40-foot cable. The other end of the cable is fastened to the sonobuoy. After the sonobuoy is in the water the hydrophone sinks to 40 feet and the remainder of the unit floats.

Sonobuoys are relatively small in physical size which creates a problem of location during operations. Three features are incorporated in the sonobuoy to aid in locating them. These are: dye markers, self-contained lights, and a beacon transmitter/receiver. Dye markers and lights are useful only within visual range. The markers are useful during daylight hours, and the lights during night operations. The beacon transmitter provides information that enables the general vicinity of the sonobuoy to be determined under conditions when the dye or lights cannot be seen.

Figure 15-27 is an expanded view of part 3 of figure 15-26. Upon hitting the water the hydrophone is released and the compartment floods with sea water. This water then activates two A batteries and the equipment is in operation within about one minute. Part 2 of figure 15-26 is a watertight compartment that contains the electronic section and a B and C battery. These batteries in conjunction with the A batteries constitute the power supply for the sonobuoy. Being watertight this section keeps the sonobuoy buoyant until the sea water dissolves a soluble plug and permits flooding of this compartment. The plug dissolves more rapidly in warm water; but in any case, several hours are required. Flooding the compartment causes the sonobuoy to sink, thus preventing recovery or observation by the enemy.

THEORY OF OPERATION

Underwater sounds picked up by the hydrophone are used to frequency modulate the transmitter section of the sonobuoy. When signals from this and other sonobuoy transmitters are demodulated in a suitable receiver,

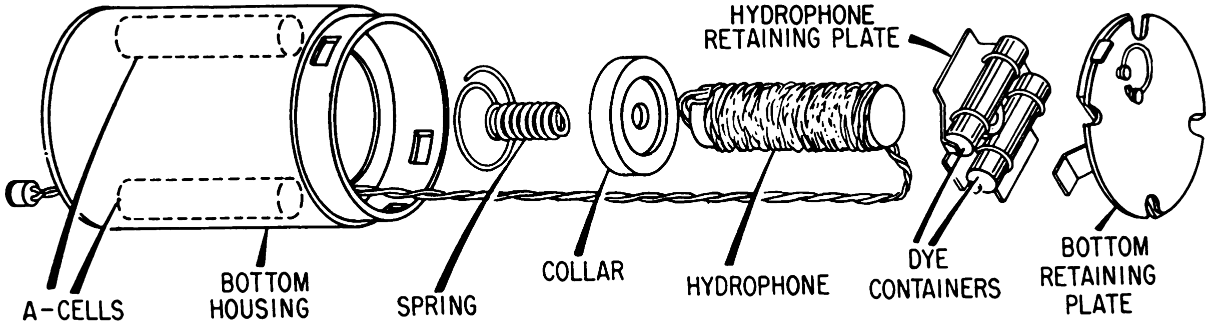


Figure 15-27.—Exploded view of bottom housing of sonobuoy.

they provide a means of identifying and locating the sound sources.

A simplified block diagram of a sonobuoy is shown in figure 15-28. Refer to this figure when studying the theory of operation of the set.

Any signal picked up by the hydrophone is fed through several stages of amplification. This strengthens the signal so that it can modulate the RF carrier signal. This amplified signal is fed to a reactance-tube modulator which acts as a variable reactance across (shunting) the oscillator tank of the RF oscillator tube. This variable reactance across the RF oscillator tank circuit varies the frequency of that oscillator tank circuit. Varying the frequency of the RF oscillator by the signal picked up by the hydrophone gives a frequency varying carrier which after several stages of multiplication, is transmitted from the FM antenna.

The frequency of the tank circuit is varied according to the type signal that is received by the hydrophone. In other words, when no signal is received by the hydrophone, the RF oscillator tank circuit is oscillating at its natural frequency. When a signal is received by the hydrophone, it is fed to the reactance-tube modulator and changes the reactance of the RF oscillator's tank circuit, thereby changing its frequency.

When no signal is being received by the hydrophone, the transmitter transmits at a

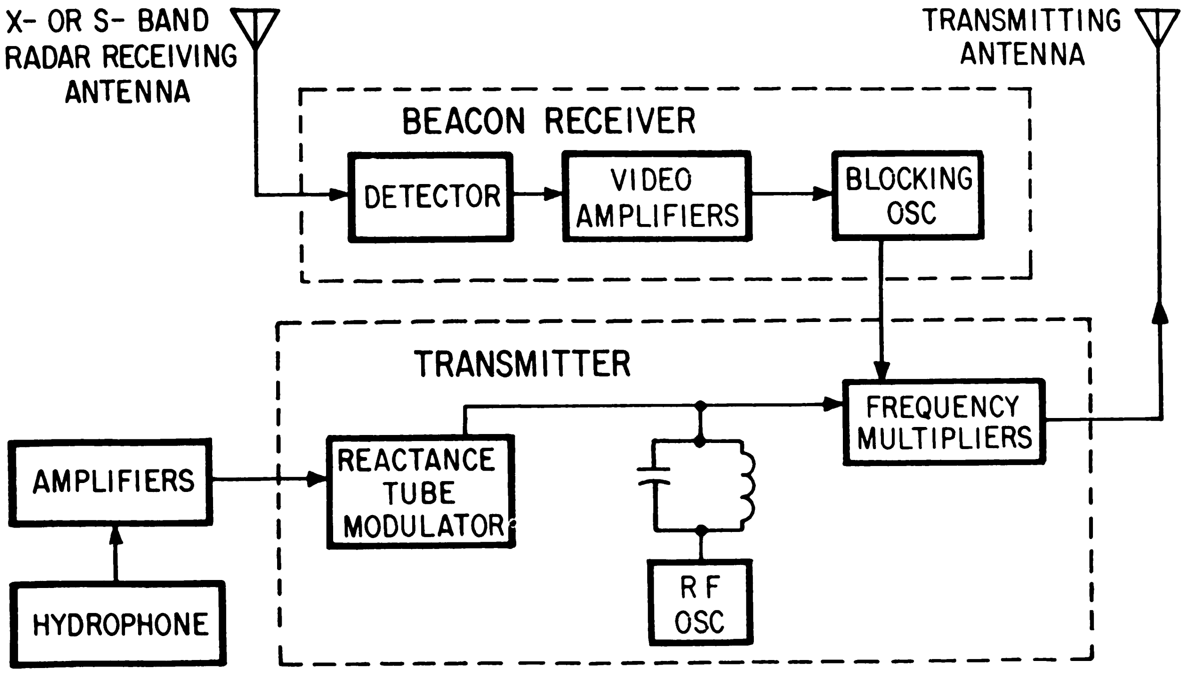


Figure 15-28.—Simplified block diagram of sonobuoy.

frequency that is determined by the natural frequency of the tank circuit. The actual frequency that is transmitted is a multiple of the RF oscillator's tank circuit frequency. The multiplier stages produce a signal that is transmitted at a frequency that lies between 162 and 174 megacycles.

When a signal is picked up by the hydrophone, it modulates the natural transmitting frequency and causes it to vary (deviate) above and below the center frequency. The extent of deviation (FM) is dependent upon the amplitude of the modulating signal. This shift in frequency is detected by a special receiver in the aircraft and is converted into useful information.

BEACON RECEIVER

The beacon receiver portion of the sonobuoy is triggered into operation when a radar's searching beam sweeps across the sonobuoy. The beacon receiver has an omnidirectional antenna that is located in the top of the floating sonobuoy. (Omnidirectional means that it will receive a signal from all directions.) This antenna responds to both X-band and S-band radar frequencies.

The interrogating radar pulse that is picked up by this antenna is rectified by the detector stage to form a pulse of voltage. This voltage pulse is amplified by the video amplifier stages so that it can trigger a blocking oscillator. This blocking oscillator is designed so that it produces a single high voltage pulse each time it is triggered. This single pulse of energy is then fed to the plate of the transmitter output tube and causes the transmitter's FM signal to be amplitude modulated. This signal is then picked up by the receiver in the aircraft and the AM portion is fed to a radarscope. The operator, by observing the scope, is able to determine the location of the sonobuoy in the water.

Since the hydrophone is omnidirectional, one sonobuoy provides very little useful information aside from the fact that there is a submarine somewhere in the water. By dropping two or more sonobuoys in a pattern, range to the submarine can be estimated and its direction of travel can be obtained. This is illustrated in figure 15-29.

For example, four sonobuoys are dropped as illustrated. Each is operating on a different frequency within the frequency band assigned to sonobuoy operations. Since each sonobuoy operates on a different frequency, the aircraft receiver is able to distinguish between the sonobuoys. Suppose a submarine travels as indicated in the figure. Sonobuoy No. 1 will receive very little or no signal; sonobuoy No. 4 will receive a very strong signal which will gradually diminish. Sonobuoys No. 2 and No. 3 will receive signals of approximately identical strength. This indicates that the submarine is located approximately the same distance from each. Thus, in the aircraft, the operator can determine the direction in which the submarine is traveling and also can approximate its location. When the aircraft locates a submarine, it can continue dropping sonobuoys so that the submarine can be continuously tracked.

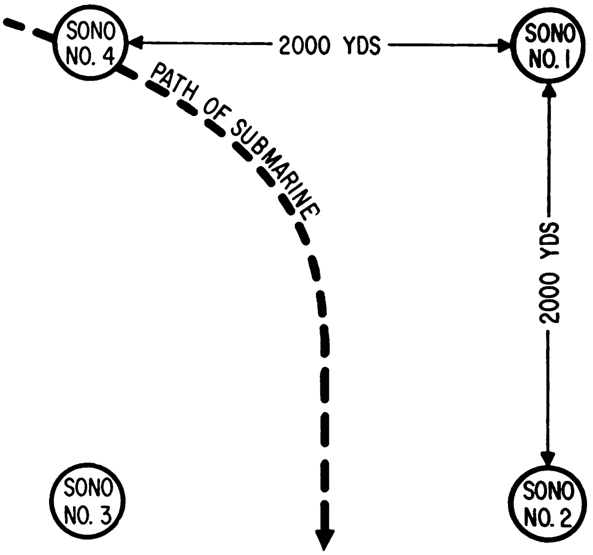


Figure 15-29.—Sonobuoy pattern.

SONOBUOY TESTING

Sonobuoys may be tested prior to use by either of two methods. Test Set AN/TSM-6 has been made specifically for testing the SSQ-2B listening sonobuoy. This test set utilizes a GOOD-POOR system to indicate if the sonobuoy under test is acceptable. Thorough testing of a sonobuoy is quickly accomplished with the TSM-6. Inherent characteristics of the SSQ-2B sonobuoy's construction make it imperative that exact testing procedures be followed; otherwise, damage to the unit can result. As in all electronics testing, read the instruction book and observe the safety precautions and operating procedure when using the TSM-6.

An alternate method of field testing may be accomplished with the following equipment: a sonobuoy receiving set, an oscilloscope, an RF generator, a multimeter, a frequency meter, two batteries, and a power cable. The multimeter is used to measure voltages of the batteries before and after power is applied to the sonobuoy.

The listening test is conducted by connecting the oscilloscope (such as a TS-239) to the beacon output of the sonobuoy receiver (ARR-26). The receiver is tuned to the channel marked on the case of the sonobuoy. Tapping the sonobuoy's case near the bottom will produce frequency modulation of the carrier. The frequency modulated signal can be observed on the test receiver or heard on a headset connected to the receiver.

The beacon test is conducted by placing the horn of the TS-13 RF signal generator about two inches from the beacon antenna of the SSQ-2B and tuning the test set for maximum output at the center of the X band. Trigger the TS-13 RF signal generator with the 800 pulses per second output from the oscilloscope. The ARR-26 will receive the beacon reply pulse and it will be displayed on the oscilloscope. The frequency of the beacon reply pulse can then be checked by using the TS-323 frequency meter.

These tests determine whether the sonobuoy "listens" and transmits a frequency-modulated signal, and if the sonobuoy properly receives and transmits in beacon operation.

QUIZ

1. The term SONAR stands for
   a. Sound Navigation and Ranging
   b. Sound Navigation and Radar
   c. Sound Navigation and Radio
   d. Sonar Navigation and Ranging

2. Doppler effect is produced by
   a. signal frequency
   b. fixed range
   c. relative motion
   d. turbulence

3. What is used in the transducer as a matching device between the crystals and salt water?
   a. Transformer
   b. Air
   c. Moisture-free oil
   d. Salt water

4. One purpose of the rotating cap of an airborne sonobuoy is to
   a. retard rate of fall
   b. scuttle sonobuoy after several hours
   c. transmit the beacon pulse
   d. pick up audio signals from the water

5. The distance between two successive rarefractions is called
   a. wavelength
   b. compression
   c. vibration
   d. high pressure

6. As the target range closes,
   a. Doppler goes up
   b. Doppler goes down
   c. Doppler opens
   d. no Doppler present

7. A main difference between a transducer and a hydrophone is that the
   a. transducer is more directional
   b. transducer is lighter
   c. transducer can be used for both listening and transmitting
   d. hydrophone is not directional

8. Two methods of locating the sonobuoy are
   a. beacon pulse and hydrophone
   b. beacon pulse and dye marker
   c. dye marker and rotating cap
   d. self-contained lights and rotating cap

9. The primary factor affecting the velocity of sound in water is
   a. temperature
   b. water pressure
   c. salinity
   d. marine life

10. As the target range opens,
    a. Doppler goes up
    b. Doppler goes down
    c. Doppler closes
    d. no Doppler present

11. The minimum number of echoes necessary to definitely establish the presence of a target are
    a. 2
    b. 4
    c. 6
    d. 8

12. The video beacon pulse is applied to the FM carrier in a sonobuoy by the
    a. reactance modulator
    b. audio amplifier
    c. crystal detector
    d. blocking oscillator

13. Sound travels approximately
    a. 4 times faster in air than in water
    b. the same speed in air as in water
    c. 4 times faster in water than in air
    d. 8,000 yards per second in water

14. The device used in sonar to emit sound waves is called a/an
    a. transmitter
    b. transducer
    c. oscillator
    d. hydrophone

15. The AQS-2 is a
    a. dipping sonar
    b. listening sonobuoy
    c. hydrophone
    d. towed sonar

16. The sonobuoy is scuttled after several hours by the action of the
    a. rotating cap
    b. soluble plug
    c. hydrophone
    d. escort ship

17. As water temperature increases,
    a. velocity of sound increases
    b. velocity of sound decreases
    c. there is less refraction of energy
    d. there is less bending of energy

18. Towed sonar can be moved at a speed of
    a. 50 knots at a 300-foot depth
    b. 300 knots at a 50-foot depth
    c. 30 knots at a 300-foot depth
    d. 50 knots at a 30-foot depth

19. How is the bearing of a target determined by dipping sonar?
    a. Train transducer for maximum echo
    b. Direction finder
    c. Doppler effect
    d. 360° scan

20. The sonobuoy transmitter operates in which frequency band?
    a. MHF
    b. HF
    c. VHF
    d. UHF

21. As sound travels through water, some of the energy is converted to heat. This is called
    a. absorption
    b. attenuation
    c. dissipation
    d. reradiation

22. The amount of absorption is determined by
    a. range
    b. bearing
    c. frequency
    d. attenuation

23. The property that causes certain metals to shrink or contract in a magnetic field is called
    a. piezoelectric effect
    b. magnetoelectric effect
    c. magnetostriction effect
    d. nickel effect

24. What determines accuracy of bearing information?
    a. Direction of echo
    b. Range of target
    c. Beam width of transducer
    d. Output power of sonar

25. The effect that causes a reflected wave to differ in frequency from the original signal is called
    a. Doppler
    b. rarefaction
    c. absorption
    d. range effect

26. The speed of sound in water is
    a. 4,800 feet per second
    b. 4,800 yards per second
    c. 186,000 miles per second
    d. 164,000 miles per second

27. The visual presentation on scanning sonar is similar to a/an
    a. PPI presentation
    b. A scope presentation
    c. B scope presentation
    d. C scope presentation

28. In order to increase the beam width of the transducer
    a. the diameter of the diaphragm is increased
    b. increase the frequency
    c. the diameter of the diaphragm is decreased
    d. increase the gain

29. Oscillations above what frequency are said to be ultrasonic?
    a. 10 kc
    b. 10 c.p.s.
    c. 20 kc
    d. 200 kc

30. For sonar use, quartz crystals are NOT used because their
    a. Q is too low
    b. bandwidth is too wide
    c. frequency response is too narrow
    d. current handling ability is low

APPENDIX 1

ELECTRONICS AND ELECTRICAL TERMS

AGONIC.--An imaginary line of the earth's surface passing through points where the magnetic declination is 0°; that is, points where the compass points to true north.

AMMETER.--An instrument for measuring the amount of electron flow in amperes.

AMPERE.--The basic unit of electrical current.

AMPERE-TURN.--The magnetizing force produced by a current of one ampere flowing through a coil of one turn.

AMPLIFICATION.--The process of increasing the strength (current, power, or voltage) of a signal.

AMPLIFICATION FACTOR (μ).--The ratio of a small change in plate voltage to a small change in grid voltage, with all other electrode voltages constant, required to produce the same small change in plate current.

AMPLIFIER.--A device used to increase the signal voltage, current, or power, generally composed of a vacuum tube and associated circuit called a stage. It may contain several stages in order to obtain a desired gain.

AMPLITUDE.--The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

ANODE.--A positive electrode; the plate of a vacuum tube.

AQUADAG.--A graphite coating on the inside of certain cathode-ray tubes for collecting secondary electrons emitted by the screen.

ARC.--A flash caused by an electric current ionizing a gas or vapor.

ARMATURE.--The rotating part of a d-c electric motor or generator. The moving part of a relay or vibrator.

ATTENUATION.--The reduction in the strength of a signal.

AUTOTRANSFORMER.--A transformer in which the primary and secondary are connected together in one winding.

AZIMUTH.--The angular measurement in a horizontal plane and in a clockwise direction, beginning at a point oriented to north.

BATTERY.--Two or more primary or secondary cells connected together electrically. The term does not apply to a single-cell.

BIAS.--Vacuum tube--the difference of potential between the control grid and the cathode; transistor--the difference of potential between the base and emitter and the base and collector; magnetic amplifier--the level of flux density in the magnetic amplifier core under no-signal condition.

BIAS WINDING.--The winding on the core of a magnetic amplifier that controls the bias.

BREAKER POINTS.--Metal contacts that open and close a circuit at timed intervals.

BRUSH.--The conducting material, usually a block of carbon, bearing against the commutator or sliprings through which the current flows in or out.

BUS BAR.--A primary power distribution point connected to the main power source.

CAPACITOR.--Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the dielectric.

CATHODE.--The electrode in a vacuum tube which is the source of electron emission; also a negative electrode.

CHOKE COIL.--A coil of low ohmic resistance and high impedance to alternating current.

CIRCUIT.--The complete path of an electric current.

CIRCUIT BREAKER.--An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULAR MIL.--An area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross section of wires.

COAXIAL CABLE.--A transmission line consisting of two conductors concentric with and insulated from each other.

COMMUTATOR.--The copper segments on the armature of a d-c motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes. It is a switching device.

CONDUCTANCE.--The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in mhos.

CONDUCTIVITY.--The ease with which a substance transmits electricity.

CONDUCTOR.--Any material suitable for carrying electric current.

CORE.--A magnetic material that affords an easy path for magnetic flux lines in a coil.

COULOMB.--A unit of electrical charge; the quantity of electrical charge created by a steady flow of one ampere for one second.

COUNTER E.M.F.—Counter electromotive force; an e.m.f. induced in a coil or armature that opposes the applied voltage.

COUNTING CIRCUIT.--A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

CURRENT LIMITER.--A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE.—One complete positive and one complete negative alternation of a current or voltage.

DETECTION.—The process of separating the modulation component from the received signal.

DIELECTRIC.—An insulator; a term that refers to the insulating material between the plates of a capacitor.

DIODE.--Vacuum tube—a two element tube that contains a cathode and plate; semiconductor—a material of either germanium or silicon that is manufactured to allow current to flow in only one direction. Diodes are used as rectifiers and detectors.

DIRECT CURRENT.—An electric current that flows in one direction only.

DISTORTION.--The production of an output waveform which is not a true reproduction of the input waveform. Distortion may consist of irregularities in amplitude, frequency, or phase.

EDDY CURRENT.—Induced circulating currents in a conducting material that are caused by a varying magnetic field.

EFFICIENCY.--The ratio of output power to input power, generally expressed as a percentage.

ELECTRICITY.—The science which treats of the phenomena and laws of things electrical.

ELECTRODE.—A terminal used to emit, collect, or control electrons and ions; a terminal at which electric current passes from one medium into another.

ELECTROLYTE.--A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET.—A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMOTIVE FORCE (E.M.F.).—The force that produces an electric current in a circuit.

ELECTRON.—A negatively charged particle of matter.

ELECTRON EMISSION.--The liberation of electrons from a body into space under the influence of heat, light, impact, chemical disintegration, or potential difference.

ELECTRONIC SWITCH.—A circuit which causes a start-and-stop action or a switching action by electronic means.

ENERGY.—The ability or capacity to do work.

EQUIVALENT CIRCUIT.—A diagrammatic arrangement of coils, resistors, and capacitors, representing the effects of a more complicated circuit in order to permit easier analysis.

FARAD.—The unit of capacitance.

FEEDBACK.—A transfer of energy from the output circuit of a device back to its input.

FIELD.—The space containing electric or magnetic lines of force.

FIELD WINDING.—The coil used to provide the magnetizing force in motors and generators.

FILTERS.—A combination of circuit elements designed to pass a definite range of frequencies, attenuating all others.

FLUORESCENCE.—The property of emitting light as the immediate result of electronic bombardment.

FLUX FIELD.—All electric or magnetic lines of force in a given region.

FREE ELECTRONS.—Electrons which are loosely held and consequently tend to move at random among the atoms of the material.

FREQUENCY.—The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current.

FULL-WAVE RECTIFIER CIRCUIT.--A circuit which utilizes both the positive and the negative alternations of an alternating current to produce a direct current.

FUSE.—A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAIN.--The ratio of the output power, voltage, or current to the input power, voltage, or current, respectively.

GALVANOMETER.—An instrument used to measure small d-c currents.

GAS TUBE.—A tube that gives certain electrical characteristics because it is filled with a certain type of gas.

GATING (CATHODE-RAY TUBE).—Applying a rectangular voltage to the grid or cathode of a CRT to sensitize it during the sweep time only.

GENERATOR.--A machine that converts mechanical energy into electrical energy.

GRID.--A wire, usually in the form of a spiral, that controls the electron flow in a vacuum tube.

GRID DETECTION.--Detection by rectification in the grid circuit of a detector.

GRID LEAK.—A high resistance connected across the grid capacitor or between the grid and the cathode to provide a d-c path from grid to cathode and to limit the accumulation of charge on the grid.

GROUND.—A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential. The chassis of a receiver or a transmitter is sometimes the common return, and therefore the "ground" of the unit.

HARMONIC.--An integral multiple of a fundamental frequency. (The second harmonic is twice the frequency of the fundamental or first harmonic.)

HENRY.—The basic unit of inductance.

HETERODYNE.—To beat or mix two signals of different frequencies.

HOLE.—In semiconductors, the space in an atom left vacant by a departed electron. Holes flow in a direction opposite to that of electrons, are considered to be current carriers, and bear a positive charge.

HORSEPOWER.—The English unit of power, equal to work done at the rate of 550 foot-pounds per second. Equal to 746 watts of electrical power.

HYSTERESIS.--A lagging of the magnetic flux in a magnetic material behind the magnetizing force which is producing it.

IMPEDANCE.--The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

INDUCTANCE.—The property of a circuit which tends to oppose a change in the existing current.

INDUCTION.—The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

INDUCTIVE REACTANCE.--The opposition to the flow of alternating or pulsating current caused by the inductance of a circuit. It is measured in ohms.

INDUCTOR.—A circuit element designed so that its inductance is its most important electrical property; a coil.

INPHASE.—Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

INTENSITY MODULATION.—The control of the brilliance of the trace on the screen of a cathode-ray tube in conformity with the signal.

INVERSELY.—Inverted or reversed in position or relationship.

ISOGONIC LINE.—An imaginary line drawn through points on the earth's surface where the magnetic deviation is equal.

JOULE.—A unit of energy or work. A joule of energy is liberated by one ampere flowing for one second through a resistance of one ohm.

KILO.—A prefix meaning 1,000.

KLYSTRON.--A tube in which oscillations are generated by the bunching of electrons (that is, velocity modulation). This tube utilizes the transit time between two given electrodes to deliver pulsating energy to a cavity resonator in order to sustain oscillations within the cavity.

LAG.--The amount one wave is behind another in time; expressed in electrical degrees.

LAMINATED CORE.—A core built up from thin sheets of metal and used in transformers and relays.

LEAD.—The opposite of LAG. Also, a wire or connection.

LINEAR.--Having an output which varies in direct proportion to the input.

LINE OF FORCE.--A line in an electric or magnetic field that shows the direction of the force.

LOAD.—The power that is being delivered by any power producing device. The equipment that uses the power from the power producing device.

MAGNETIC AMPLIFIER.--A saturable reactor type device that is used in a circuit to amplify or control.

MAGNETIC CIRCUIT.--The complete path of magnetic lines of force.

MAGNETIC FIELD.—The space in which a magnetic force exists.

MAGNETIC FLUX.—The total number of lines of force issuing from a pole of a magnet.

MAGNETIZE.--To convert a material into a magnet by causing the molecules to rearrange.

MAGNETO.—A generator which produces alternating current and has a permanent magnet as its field.

MAGNETRON.—A vacuum-tube oscillator containing two electrodes, in which the flow of electrons from cathode to anode is controlled by an externally applied magnetic field.

MEGGER.—A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operated d-c generator used as an ohmmeter.

MEGOHM.—A million ohms.

MICRO.--A prefix meaning one-millionth.

MILLI.—A prefix meaning one-thousandth.

MILLIAMMETER.--An ammeter that measures current in thousandths of an ampere.

MODULATION.--The process of varying the amplitude (amplitude modulation), the frequency (frequency modulation), or the phase (phase modulation) of a carrier wave in accordance with other signals in order to convey intelligence. The modulating signal may be an audiofrequency signal, video signal (as in television), or electrical pulses or tones to operate relays, etc.

MOTOR-GENERATOR.--A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

MUTUAL INDUCTANCE.--A circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of the other.

NEGATIVE CHARGE.—The electrical charge carried by a body which has an excess of electrons.

NEUTRONS.--A particle having the weight of a proton but carrying no electric charge. It is located in the nucleus of an atom.

NONLINEAR.--Having an output which does not vary in direct proportion to the input.

NUCLEUS.--The central part of an atom that is mainly comprised of protons and neutrons. It is the part of the atom that has the most mass.

NULL.—Zero.

OHM.—The unit of electrical resistance.

OHMMETER.—An instrument for directly measuring resistance in ohms.

OSCILLOSCOPE.--An instrument for showing, visually, graphical representations of the waveforms encountered in electrical circuits.

OVERLOAD.—A load greater than the rated load of an electrical device.

PERMALLOY.—An alloy of nickel and iron having an abnormally high magnetic permeability.

PERMEABILITY.—A measure of the ease with which magnetic lines of force can flow through a material as compared to air.

PHASE DIFFERENCE.--The time in electrical degrees by which one wave leads or lags another.

PHOSPHORESCENCE.--The property of emitting light for some time after excitation by electronic bombardment.

PLATE.--The principal electrode in a tube to which the electron stream is attracted.

PLATE CURRENT.--The current flowing in the plate circuit of a vacuum tube.

PLATE DETECTION.--The operation of a vacuum-tube detector at or near cutoff so that the input signal is rectified in the plate circuit.

PLATE RESISTANCE (r_p).—The internal resistance to the flow of alternating current between the cathode and plate of a tube. It is equal to a small change in plate voltage divided by the corresponding change in plate current, and is expressed in ohms. It is also called a-c resistance, internal impedance, plate impedance, and dynamic plate impedance. The static plate resistance, or resistance to the flow of direct current, is a different value. It is denoted by r_p.

POLARITY.—The character of having magnetic poles, or electric charges.

POLE.—The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. An electrode of a battery.

POLYPHASE.--A circuit that utilizes more than one phase of alternating current.

POSITIVE CHARGE.—The electrical charge carried by a body which has become deficient in electrons.

POTENTIAL.—The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIOMETER.--A variable voltage divider; a resistor which has a variable contact arm so that any portion of the potential applied between its ends may be selected.

POWER.—The rate of doing work or the rate of expanding energy. The unit of electrical power is the watt.

POWER FACTOR.—The ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

PRIME MOVER.—The source of mechanical power used to drive the rotor of a generator.

PROTON.—A positively charged particle in the nucleus of an atom.

PUSH-PULL CIRCUIT.—A push-pull circuit usually refers to an amplifier circuit using two vacuum tubes in such a fashion that when one vacuum tube is operating on a positive alternation, the other vacuum tube operates on a negative alternation.

RATIO.—The value obtained by dividing one number by another, indicating their relative proportions.

REACTANCE.—The opposition offered to the flow of an alternating current by the inductance, capacitance, or both, in any circuit.

RECIPROCAL.--The value obtained by dividing the number 1 by any quantity.

RECTIFIERS.--Devices used to change alternating current to unidirectional current. These may be vacuum tubes, semiconductors such as germanium and silicon, dry-disk rectifiers such as selenium and copper-oxide, and also certain types of crystal.

RELAXATION OSCILLATOR.--A circuit for the generation of nonsinusoidal waves by gradually storing and quickly releasing energy either in the electric field of a capacitor or in the magnetic field of an inductor.

RELAY.--An electromechanical switching device that can be used as a remote control.

RELUCTANCE.—A measure of the opposition that a material offers to magnetic lines of force.

RESISTANCE.—The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESISTOR.—A circuit element whose chief characteristic is resistance; used to oppose the flow of current.

RESONANCE.—The condition existing in a circuit in which the inductive and capacitive reactances cancel each other.

RESONANCE CURVE.—A graphical representation of the manner in which a resonant circuit responds to various frequencies at and near the resonant frequency.

RETENTIVITY.—The measure of the ability of a material to hold its magnetism.

RHEOSTAT.—A variable resistor.

SATURABLE REACTOR.—A control device that uses a small d-c current to control a large a-c current by controlling core flux density.

SATURATION.—The condition existing in any circuit when an increase in the driving signal produces no further change in the resultant effect.

SELF-INDUCTION.—The process by which a circuit induces an e.m.f. into itself by its own magnetic field.

SERIES-WOUND.—A motor or generator in which the armature is wired in series with the field winding.

SERVO.—A device used to convert a small movement into one of greater movement or force.

SERVOMECHANISM.—A closed-loop system that produces a force to position an object in accordance with the information that originates at the input.

SOLENOID.—An electromagnetic coil that contains a movable plunger.

SPACE CHARGE.—The cloud of electrons existing in the space between the cathode and plate in a vacuum tube, formed by the electrons emitted from the cathode in excess of those immediately attracted to the plate.

STANDING WAVE.—A distribution of current and voltage on a transmission line formed by two sets of waves traveling in opposite directions, and characterized by the presence of a number of points of successive maxima and minima in the distribution curves.

STATIC.—A fixed nonvarying condition; without motion.

SWEEP CIRCUIT.—The part of a cathode-ray oscilloscope which provides a time-reference base.

SYNCHRO SYSTEM.—An electrical system that gives remote indications or control by means of self-synchronizing motors.

SYNCHRONOUS.—Happening at the same time; having the same period and phase.

TACHOMETER.—An instrument for indicating revolutions per minute.

TERTIARY WINDING.—A third winding on a transformer or magnetic amplifier that is used as a second control winding.

THERMISTOR.—A resistor that is used to compensate for temperature variations in a circuit.

THERMOCOUPLE.—A junction of two dissimilar metals that produces a voltage when heated.

TRACE.—A visible line or lines appearing on the screen of a cathode-ray tube in operation.

TRANSFORMER.—A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

TRANSMISSION LINES.—Any conductor or system of conductors used to carry electrical energy from its source to a load.

TRIGGERING.—Starting an action in another circuit, which then functions for a time under its own control.

TRIODE.—A three-electrode vacuum tube, containing a cathode, control grid, and plate.

TUNED CIRCUIT.—A resonant circuit.

VACUUM TUBE.—An evacuated envelope containing two or more electrodes.

VECTOR.—A line used to represent both direction and magnitude.

VIDEO AMPLIFIER.—A circuit capable of amplifying a very wide range of frequencies, including and exceeding the audio band of frequencies.

VOLT.—The unit of electrical potential.

WATT.—The unit of electrical power.

WATTMETER.—An instrument for measuring electric power in watts.

WAVEFORM.—The shape of the wave obtained when instantaneous values of an a-c quantity are plotted against time in rectangular coordinates.

WAVELENGTH (λ).—The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

APPENDIX II

GREEK ALPHABET

Name	Capital	Lower case	Designates
Alpha	A	α	Angles.
Beta.	B	β	Angles, flux density.
Gamma.	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon.	E	ϵ	Base of natural logarithms (2.71828).
Zeta.	Z	ζ	Impedance, coefficients, coordinates.
Eta	H	η	Hysteresis coefficient, efficiency.
Theta	Θ	θ	Phase angle.
Iota	I	ι	
Kappa.	K	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu.	M	μ	Permeability, micro, amplification factor.
Nu	N	ν	Reluctivity.
Xi	Ξ	ξ	
Omicon.	O	o	
Pi	Π	π	3.1416
Rho	P	ρ	Resistivity.
Sigma.	Σ	σ	
Tau	T	τ	Time constant, time-phase displacement.
Upsilon.	Υ	υ	
Phi	Φ	ϕ	Angles, magnetic flux.
Chi	X	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity ($2\pi f$).

APPENDIX III
FORMULAS

Ohm's Law for D-C circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or emf	Gilberts, F, or mmf.
Flow	Ampere, I	Flux, Φ, in maxwells.
Opposition	Ohms, R.	Reluctance, $\mathfrak{R}$.
Law	Ohms law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathfrak{R}}$.
Intensity of force	Volts per cm of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density	Current density—for example, amperes per cm^2.	Flux density—for example, lines per cm^2, or gausses.

R-L Circuit Time Constant equals

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

R-C Circuit Time Constants equals

R (ohms) × C (farads) = t (seconds)

R (megohms) × C (microfarads) = t (seconds)

R (ohms) × C (microfarads) = t (microseconds)

R (megohms) × C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$$

Capacitors in Parallel $C_T = C_1 + C_2 \ldots$

Capacitive Reactance $(X_C = \frac{1}{2\pi fC})$

Impedance in an R-C Circuit (Series)

$$Z = \sqrt{R^2 + X_C^2}$$

Inductors in Series

$$L_T = L_1 + L_2 \ldots$$

(No coupling between coils)

Inductors in Parallel

Two inductors

$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

(No coupling between coils)

More than two

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots$$

(No coupling between coils)

Inductive Reactance

$$X_L = 2\pi f L$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an R-L Circuit (Series)

$$Z = \sqrt{R^2 + X_L{}^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637 E_{max}$$

Effective or r.m.s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707 E_{max} = 1.11 E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2} \quad E_{eff} = 1.414 E_{eff} = 1.57 E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

Power in A-C Circuit

Apparent power = EI

True power (P = EI cos θ = EI × P.F.

Power Factor

$$P.F. = \frac{P}{EI} = \cos\theta$$

$$\cos\theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44\ BAfN10^{-8}$$

Turns ratio equals

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With Wye connected windings

$$E_{line} = 1.732 E_{coil} = \sqrt{3}\ E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732 I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil} I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732 E_{line} I_{line}$$

(To convert to true power multiply by $\cos\theta$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$A \text{ (at any frequency)} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L^2}{R} = QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} (i_p \text{ constant})$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \quad (e_p \text{ constant})$$

Decibels

Power ratio

$$db = 10 \log_{10} \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log_{10} \frac{I_2\sqrt{R_2}}{I_1\sqrt{R_1}}$$

$$db = 20 \log_{10} \frac{E_2\sqrt{R_1}}{E_1\sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula.

When reference level is one milliwatt

$$dbm = 10 \log_{10} \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$\text{r.p.m.} = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

Radar Power Relationships

$$\text{Duty cycle} = \frac{\text{average power}}{\text{peak power}} = \frac{\text{pulse width}}{\text{pulse repetition time}}$$

Average power = peak power × duty cycle

$$\text{Peak power} = \frac{\text{average power} \times 10^6}{\text{pulse width in } \mu\text{sec.} \times \text{PRF}}$$

APPENDIX IV
LAWS OF EXPONENTS

The following table shows some multiples of 10 and their equivalent powers of ten which are used to write a number in scientific form.

Number	Powers of Ten	Number	Powers of Ten
100,000 =	10^5	0.00001 =	10^{-5}
10,000 =	10^4	0.0001 =	10^{-4}
1,000 =	10^3	0.001 =	10^{-3}
100 =	10^2	0.01 =	10^{-2}
10 =	10^1	0.1 =	10^{-1}
1 =	10^0	1. =	10^{-0}

To multiply like (with same base) exponential quantities, add the exponents. In the language of algebra the rule is $a^m \times a^n = a^{m+n}$

$$10^4 + 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2 =$$

$$24.756 \times 10^{-1} = 2.4756$$

To divide like exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or } 10^8 + 10^2 = 10^6$$

$$3{,}000 + 0.015 = (3 \times 10^3) + (1.5 \times 10^{-2}) =$$

$$2 \times 10^5 = 200{,}000$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra $(x^m)^n = x^{mn}$.

$$(10^3)^4 = 10^{3\times 4} = 10^{12}$$

$$2{,}500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6{,}250{,}000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0 = 1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra

$$x^{-a} = \frac{1}{x^a}$$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3{,}000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x^3 \qquad \sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

APPENDIX V

ANSWERS TO QUIZZES

Chapter 1

THE AVIATION ELECTRONICS TECHNICIAN

1. d.
2. c.
3. d.
4. b.
5. c.
6. d.
7. b.
8. c.
9. c.
10. d.

Chapter 2

SAFETY PRECAUTIONS IN ELECTRONICS MAINTENANCE

1. a.
2. d.
3. a.
4. c.
5. b.
6. c.
7. b.
8. c.
9. a.
10. a.
11. d.
12. c.
13. a.
14. c.
15. b.
16. c.
17. b.
18. c.
19. False
20. False
21. True
22. True

Chapter 3

PUBLICATIONS, RECORDS AND REPORTS, PROCUREMENT OF EQUIPMENT

1. Equipment History Card
2. a.
3. a.
4. a complete installation
5. HOI, HSI, O/H, and IPB
6. d.
7. b.
8. b.
9. c.
10. Handbook of Operating Instructions
11. airborne installation
12. d.
13. c.
14. d.
15. a.
16. I
17. radio equipment
18. Immediate Action, Urgent Action, and Routine Action.
19. Naval Aviation Electronics Service Unit
20. communication equipment
21. a.
22. work log
23. Instructions and Notices
24. the model number
25. Electronic Failure Report (EFR) and Failure, Unsatisfactory and Removal Report (FUR)

Chapter 4

TRANSISTORS AND MAGNETIC AMPLIFIERS

1. c.
2. b.
3. a.
4. b.
5. c.
6. a.
7. d.
8. a.
9. b.
10. c.
11. d.
12. c.
13. d.
14. c.
15. a.
16. c.
17. f.
18. g.
19. h.
20. a.
21. i.
22. e.
23. b.
24. d.
25. d.
26. a.
27. c.
28. a.
29. c.
30. a.
31. b.
32. c.
33. d.
34. c.

Chapter 5

FUNDAMENTALS OF COMPUTERS

1. b.
2. d.
3. b.
4. a.
5. b.
6. c.
7. b.
8. d.
9. d.
10. a.
11. b.
12. c.
13. c.
14. b.
15. b.
16. c.
17. b.
18. b.
19. a.
20. a.
21. a.
22. a.
23. c.
24. c.
25. d.
26. d.
27. d.
28. d.
29. d.
30. a.
31. b.
32. d.
33. b.
34. b.
35. c.
36. a.
37. a.

Chapter 6

AIRCRAFT ELECTRIC POWER SYSTEMS

1. d.
2. b.
3. b.
4. c.
5. b.
6. b.
7. d.
8. b.
9. d.
10. d.
11. d.
12. b.
13. c.
14. c.
15. d.
16. c.
17. c.
18. d.
19. a.
20. b.
21. b.
22. b.
23. c.

Chapter 7

ELECTRONIC TEST EQUIPMENT

1. c.
2. c.
3. b.
4. d.
5. a.
6. a.
7. c.
8. b.
9. a.
10. d.
11. c.
12. a.
13. c.
14. d.
15. b.
16. b.
17. c.
18. c.
19. c.
20. a.
21. a.
22. d.
23. b.
24. d.
25. d.
26. c.
27. a.
28. b.
29. a.
30. d.
31. a.

Chapter 8

AIRCRAFT ELECTRONICS MAINTENANCE

1. c.
2. b.
3. a.
4. c.
5. b.
6. c.
7. d.
8. a.
9. d.
10. d.
11. c.
12. b.
13. b.
14. b.
15. c.
16. b.
17. a.
18. d.
19. d.
20. a.
21. d.
22. b.
23. c.
24. a.
25. a.
26. c.
27. a.
28. b.
29. b.
30. c.

Chapter 9

AIRBORNE COMMUNICATION EQUIPMENT

b.
d.
c.
d.
c.
c.
a.
8. c.
9. d.
10. d.
11. b.
12. a.
13. d.
14. b.
15. d.
16. a.
17. d.
18. a.
19. b.
20. a.
21. c.
22. c.
23. c.
24. a.
25. b.

Chapter 10

AIRBORNE COMMUNICATION EQUIPMENT--CONTINUED

c.
b.
c.
c.
a.
b.
7. b.
8. d.
9. b.
10. a.
11. b.
12. c.
13. d.
14. c.
15. d.
16. c.
17. b.
18. c.
19. c.
20. d.
21. c.
22. d.

Chapter 11

AIRBORNE ELECTRONIC NAVIGATION EQUIPMENT

a.
b.
c.
c.
b.
b.
a.
b.
a.
10. d.
11. c.
12. b.
13. a.
14. b.
15. c.
16. c.
17. c.
18. b.
19. a.
20. d.
21. c.
22. a.
23. c.
24. a.
25. a.
26. c.
27. a.
28. a.
29. a.
30. d.
31. c.
32. d.
33. b.
34. c.

Chapter 12

AIRBORNE RADAR

c.
b.
b.
a.
d.
c.
c.
8. d.
9. b.
10. c.
11. b.
12. c.
13. a.
14. d.
15. c.
16. c.
17. d.
18. d.
19. c.
20. b.
21. c.
22. a.
23. b.
24. c.
25. c.

Chapter 13

ELECTRONIC COUNTERMEASURES

c.
b.
d.
b.
a.
d.
7. c.
8. d.
9. d.
10. c.
11. a.
12. b.
13. d.
14. d.
15. d.
16. a.
17. c.
18. a.
19. d.
20. a.
21. b.

Chapter 14

MAGNETIC AIRBORNE DETECTION EQUIPMENT

1. b.
2. c.
3. b.
4. b.
5. c.
6. c.
7. a.
8. b.
9. b.
10. c.
11. c.
12. c.
13. c.
14. d.
15. c
16. c
17. c
18. d

Chapter 15

AIRBORNE SONAR AND SONOBUOYS

1. a.
2. c.
3. c.
4. a.
5. a.
6. a.
7. c.
8. b.
9. a.
10. b.
11. b.
12. d.
13. c.
14. b.
15. d.
16. b.
17. a.
18. a.
19. a.
20. c.
21. a.
22. c.
23. c.
24. c
25. a
26. a
27. a
28. c
29. c
30. c

APPENDIX VI

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION ELECTRONICS TECHNICIAN (AT)

(Extracted from NavPers 18068 (Revised) thru Change 13)

Rating Code No. 6300

PROFESSIONAL REQUIREMENTS

General Service Rating

Scope

Aviation Electronics Technicians test, maintain, and repair aviation electronic equipment; inspect, clean, lubricate, and make operational tests and adjustments of communication, navigation, search, identification, electronic countermeasures detection, and relay equipment; remove and reinstall components, assemblies, and subassemblies; calibrate, repair and make performance measurements; make detailed mechanical, electrical, and electronic casualty analysis; aline communication, navigation, search, identification, display, and relay equipments; make authorized repairs and adjustments to associated test equipment.

Emergency Service Ratings

AVIATION ELECTRONICS TECHNICIANS R (Radar),
Rating Code No. 6304 . . . . ATR

Test, maintain, and repair aviation electronic equipment including radar, radar altimeters, radar display, radar relay, and identification equipment; inspect, clean, lubricate, and make operational tests and adjustments of search, identification, radar detection, and relay equipments; remove and install/reinstall components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements; make detailed mechanical, electrical, and electronic casualty analysis; aline radar search, display, and relay equipments and identification equipment; make authorized repairs and adjustments to associated test equipment.

AVIATION ELECTRONICS TECHNICIANS S (ASW),
Rating Code No. 6305 . . . . ATS

Test, aline, maintain, and repair aviation electronic anti-submarine detection and reconnaissance equipment other than radar; inspect, clean, lubricate, and make operational tests and adjustments of electronic countermeasures (ECM), magnetic airborne detection (MAD), sonobuoys, and related equipments, and airborne sonar and related equipments; remove, install/reinstall components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements; make detailed mechanical, electrical, and electronic casualty analysis; make authorized repairs and adjustments to associated test equipment.

AVIATION ELECTRONICS TECHNICIANS N (Communication and Navigation Equipment), Rating Code No. 6306 . . . . ATN

Test, maintain, and repair aviation electronic communication and navigation equipment; inspect, clean, lubricate, and make operational tests of communication and navigation equipments; remove and install/reinstall components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements; make detailed mechanical, electrical, and electronic casualty analysis; make authorized repairs and adjustments to associated test equipment.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classifications, NavPers 15105 (Revised), codes AT-6600 through AT-6699.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
100 PRACTICAL FACTORS				
101 Operational				
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns.	3	3	3	3
2. Energize, secure, set operating controls, make operator's adjustments, and read and interpret dials, built-in meters, and cathode ray tube presentations on:				
*a. Aviation radar equipment.	3	3	-	-
*b. Aviation ASW equipment	3	-	3	-
*c. Aviation communication and navigation equipment	3	-	-	3
102 MAINTENANCE AND/OR REPAIR				
1. Select and use hand tools and small portable power tools provided for maintenance and repair of:				
a. Aviation radar equipment.	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
2. Inspect and clean commutators and slip ring assemblies; inspect and replace brushes . .	3	3	3	3
3. Lubricate and clean the following in accordance with aviation electronic technical and maintenance publications:				
a. Aviation radar equipment.	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3

---

*Where terms "aviation radar equipment," "aviation ASW equipment," and "aviation communication and navigation equipment" are used in the qualifications items, these equipments are defined in terms of the scopes of emergency service ratings.

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
102 MAINTENANCE AND/OR REPAIR--Continued				
4. Operate the following test equipment in performance of line maintenance:				
a. Ohmmeter	3	3	3	3
b. Ammeter	3	3	3	3
c. Voltmeter	3	3	3	3
d. Megger	3	3	3	3
e. Tube tester	3	3	3	3
f. Frequency meter	3	3	3	3
g. Multimeter	3	3	3	3
h. Oscilloscope	3	3	3	3
i. RF signal generator	3	3	3	3
j. AF signal generator	3	3	3	3
k. Sonobuoy test set	-	-	3	-
l. Magnetic detection test set	-	-	3	-
m. Output meter	-	-	-	3
5. Make tests on the following for short circuits, grounds, and continuity of interconnecting cables between components, and report results:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
6. Localize equipment casualties in aircraft to removable component in:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
7. Make electrical connections and splices including soldered joints	3	3	3	3
8. Remove, reinstall, inspect, and test for correct installation in aircraft, components of:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
9. Test and replace electron tubes, fuses, wiring, lamps, and connectors (excluding potting process)	3	3	3	3
10. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams of electrical circuits found in aircraft and equipment maintenance publications where applicable to maintenance and repair of:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
11. Locate and identify components of the following electronic equipment in aircraft by reference to block diagrams and mechanical drawings:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
102 MAINTENANCE AND/OR REPAIR--Continued				
12. Operate the following test equipment in performance of shop maintenance:				
a. Vacuum tube voltmeter	2	2	2	2
b. Spectrum analyzer	2	2	-	-
c. Signal generators	2	2	2	2
d. Frequency meters	2	2	2	2
e. RF wattmeter	2	2	2	2
f. Echo box.	2	2	-	-
13. Test the following aviation electronic equipment for short circuits, grounds, and continuity in electronic circuits; measure electrical quantities such as voltage, current, power, frequency, and phase angle, and compare with established values; trace signals, using an oscilloscope; determine wave forms and compare with established or required forms:				
a. Aviation radar equipment.	2	2	-	-
b. Aviation ASW equipment	2	-	2	-
c. Aviation communication and navigation equipment	2	-	-	2
14. Localize equipment casualties to detailed parts such as resistors, plug-in units, potentiometers, synchros, and tubes within a component, assembly, and subassembly in:				
a. Aviation radar equipment.	2	2	-	-
b. Aviation ASW equipment	2	-	2	-
c. Aviation communication and navigation equipment	2	-	-	2
15. Effect alterations or modifications to aviation electronic material in accordance with Aircraft Service Changes and Electronic Material Changes	2	2	2	2
16. Repair and adjust aviation electronic equipment circuitry by replacement or repair of assemblies, subassemblies, or detailed parts	2	2	2	2
17. Read and interpret electronic wiring and schematic diagrams, waveform charts, and voltage and resistance charts in aviation electronic technical and maintenance publications	2	2	2	2
18. Evaluate test equipment for correct operations; make authorized repairs and calibrations	1	1	1	1
19. Diagnose and localize casualties within the following:				
a. Aviation radar systems	1	1	-	-
b. Aviation ASW systems.	1	-	1	-
c. Aviation communication and navigation systems	1	-	-	1
20. Adjust and aline parts or circuitry in components, assemblies, or subassemblies to conform to allowable limits	1	1	1	1
21. Accomplish quantitative performance checks on systems and compare with prescribed standards	1	1	1	1

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
102 MAINTENANCE AND/OR REPAIR--Continued				
22. Evaluate electrical and electronic tests made on aircraft, aviation electronic equipment, components, assemblies, and subassemblies; reduce data and make corrections; compare values against prescribed performance criteria	C	C	C	C
23. Evaluate repaired, overhauled, or newly installed aviation electronic radar equipment or components thereof for proper performance	C	C	-	-
24. Evaluate repaired, overhauled, or newly installed aviation electronic ASW equipment or components thereof for proper performance	C	-	C	-
25. Evaluate repaired, overhauled, or newly installed aviation electronic communication and navigation equipment	C	-	-	C
26. Screen for feasibility of local repairs: Equipment, components, assemblies, subassemblies, or parts recommended for exchange	C	C	C	C
103 ADMINISTRATIVE AND/OR CLERICAL				
1. Record test data and work accomplished in required work logs; complete checklists	3	3	3	3
2. Prepare reports of equipment failure; prepare shop requisitions for spare parts, tools, and material needed to repair:				
a. Aviation radar equipment	2	2	-	-
b. Aviation ASW equipment	2	-	2	-
c. Aviation communication and navigation equipment	2	-	-	2
3. Evaluate shop and equipment logs, completed equipment checklists, reports of equipment failure; requisitions for spare parts, tools, and material in repairing:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
4. Take, record, and report inventory of spare parts, tools, test equipment, and materials in shop and shop storeroom	1	1	1	1
5. Train and supervise personnel in maintenance and repair of:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
6. Organize and administer a shop for maintenance and repair of:				
a. Aviation radar equipment	C	C	-	-
b. Aviation ASW equipment	C	-	C	-
c. Aviation communication and navigation equipment	C	-	-	C
7. Prepare reports covering shopwork accomplished, materials used, and status and condition of aviation electronic equipment and test equipment	C	C	C	C

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
103 ADMINISTRATIVE AND/OR CLERICAL--Continued				
8. Evaluate inventories in terms of shop requirements and prepare requisitions to replenish stock or to obtain new items	C	C	C	C
200 EXAMINATION SUBJECTS				
201 OPERATIONAL				
1. Effects of electrical shock, method of resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3	3	3	3
2. Safety precautions to be observed when working on the line and in a hangar or shop, as set forth in Chapter 3, U. S. Navy Safety Precautions (OPNAV 34P1)	3	3	3	3
3. Electrical and electronic safety precautions applicable to aviation personnel as set forth in Chapter 18, U. S. Navy Safety Precautions (OPNAV 34P1)	3	3	3	3
202 MAINTENANCE AND/OR REPAIR				
1. Types and purposes of hand tools and small portable power tools provided for use in maintenance and repair of:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
2. Function of the following test equipment:				
a. Ohmmeter	3	3	3	3
b. Ammeter	3	3	3	3
c. Voltmeter	3	3	3	3
d. Megger	3	3	3	3
e. Multimeter	3	3	3	3
f. Tube tester	3	3	3	3
g. Echo box	3	3	-	-
h. Frequency meters (portable line maintenance type)	3	3	3	3
i. Oscilloscope	3	3	3	3
j. RF signal generator	3	3	3	3
k. AF signal generator	3	3	3	3
l. Crystal checker	3	3	3	-
m. Sonobuoy test set	-	-	3	-
n. Magnetic detection test set	-	-	3	-
o. Output meter	-	-	-	3
3. Operating principles of voltmeter, ammeter, and ohmmeter (but not vacuum tube voltmeter), including:				
a. D'Arsonval meter movement	3	3	3	3
b. Shunts and multipliers	3	3	3	3
c. Use of thermocouples and rectifiers in a.c. meters	3	3	3	3
4. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3	3	3	3

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
202 MAINTENANCE AND/OR REPAIR--Continued				
5. Soldering materials and methods of soldering used in maintenance and repair of:				
a. Aviation radar equipment.	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
6. Types of information shown and meaning of electrical and electronic symbols used in schematic and block diagrams of:				
a. Aviation radar equipment.	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
7. Units of electrical measurement including:				
a. Volt	3	3	3	3
b. Ampere	3	3	3	3
c. Ohm.	3	3	3	3
d. Watt.	3	3	3	3
e. Volt-ampere	3	3	3	3
f. Henry.	3	3	3	3
g. Farad.	3	3	3	3
h. Cycle	3	3	3	3
i. Ampere-turn	3	3	3	3
j. Prefixing of mega, kilo, milli, and micro	3	3	3	3
k. Gamma.	-	-	3	-
l. Oersted	-	-	3	-
m. Gauss.	-	-	3	-
8. Meaning of:				
a. Conductors and insulators	3	3	3	3
b. Field intensity	3	3	3	3
c. Flux density	3	3	3	3
d. Permeability	3	3	3	3
e. Hysteresis and eddy currents	3	3	3	3
f. Self and mutual inductance	3	3	3	3
g. Electromagnetic induction	3	3	3	3
h. Power factor	3	3	3	3
i. Reactance	3	3	3	3
j. Impedance.	3	3	3	3
k. Capacitance.	3	3	3	3
l. Frequency.	3	3	3	3
m. Phase.	3	3	3	3
n. Time constant	3	3	3	3
9. System of assigning "AN" letter-number combinations as designation for electronic equipment	3	3	3	3
10. RMA color coding systems for capacitors and resistors	3	3	3	3
11. Operating principles of superheterodyne receivers	3	3	3	3
12. Function of the following in electrical/electronic circuits:				
a. Resistors	3	3	3	3
b. Rheostats and potentiometers	3	3	3	3
c. Solenoids	3	3	3	3
d. Inductors	3	3	3	3
e. Capacitors	3	3	3	3
f. Fuses.	3	3	3	3

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
MAINTENANCE AND/OR REPAIR—Continued				
g. Switches	3	3	3	3
h. Reactors	3	3	3	3
i. Transformers	3	3	3	3
j. Relays	3	3	3	3
k. Synchros	-	3	3	-
l. Servomechanisms	-	3	3	-
3. Types of electron tubes used in electronic circuits and operating principles of diode, triode, tetrode, pentode, and mixer/converter tubes	3	3	3	3
4. Relationship of resistance, inductance, and capacitance in a.c. circuits	3	3	3	3
5. Relationship of current, voltage, and impedance in a.c. circuits	3	3	3	3
6. Relationship of length and cross-sectional area to resistance of a conductor	3	3	3	3
7. Relationship of resistance, temperature, and current in an electrical conductor	3	3	3	3
8. Calculation of current, voltage, and resistance in d.c. series and parallel circuits containing not more than four elements	3	3	3	3
9. Component parts of motors, generators, and alternators; application of laws of magnetism to electrical rotating machinery	3	3	3	3
20. Effects of meter sensitivity in circuit voltage measurement	3	3	3	3
21. Function and operating principles of the following:				
a. DC power supplies (half-wave, full-wave, and bridge-type rectifiers, voltage doublers, and capacitor and choke input filters)	3	3	3	3
b. DC voltage regulators	3	3	3	3
22. Function of the following shop-type test equipment:				
a. Vacuum tube voltmeter	2	2	2	2
b. Spectrum analyzer	2	2	-	-
c. Signal generators	2	2	2	2
d. Frequency meters	2	2	2	2
e. RF wattmeter	2	2	2	2
f. MAD equipment analyzer	-	-	2	-
g. Sonar test set	-	-	2	-
h. Permeability shield cans	-	-	2	-
i. Magnet set	-	-	2	-
23. Circuit loading effects of test equipment.	2	2	2	2
24. Function and operating principles of the following electronic circuits:				
a. Audio amplifiers	2	2	2	2
b. Video amplifiers	2	2	2	2
c. RF amplifiers	2	2	2	2
d. IF amplifiers	2	2	2	2
e. Cathode followers	2	2	2	2
f. Oscillators--Hartley, crystal-controlled, Colpitts, TPTG, and electron-coupled	2	2	2	2
g. Detectors: diode and crystal	2	2	2	2
h. Mixer/converter	2	2	2	2
i. Frequency multipliers	2	2	2	2
j. Modulators	2	2	2	2

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
202 MAINTENANCE AND/OR REPAIR—Continued				
25. Relationship of current, voltage, and impedance in series and parallel resonant circuits at, above, and below resonance	2	2	2	2
26. Relationship of reluctance, flux, and magnetomotive force in a.c. and d.c. magnetic circuits	2	2	2	2
27. Calculation of current, voltage, phase angle, impedance, and resonance in a.c. series and parallel circuits containing not more than four elements	2	2	2	2
28. Operating principles of test equipment authorized for repair and/or calibration of:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
29. Methods and equipment used in adjustment and alinement of parts or circuitry in components, assemblies, or subassemblies, of the following, to conform to allowable limits:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
30. Operating principles of the following:				
a. Tuned coupling circuits	1	1	1	1
b. Impedance matching	1	1	1	1
c. Phase shifters	1	1	1	1
d. Differentiators	1	1	1	1
e. Integrators	1	1	1	1
f. Oscillators: (blocking and Wein-Bridge)	1	1	1	1
g. Trigger circuits and multivibrators	1	1	1	1
h. Coincidence circuits	1	1	1	1
i. Limiters: (noise and pulse)	1	1	1	1
j. Clippers	1	1	1	1
k. Discriminators	1	1	1	1
l. AGC and AFC circuits	1	1	1	1
m. Squelch circuits	1	1	1	1
n. Counting circuits	1	1	1	1
o. Sawtooth generators	1	1	1	1
p. Peakers	1	1	1	1
q. Clampers	1	1	1	1
r. Delay lines	1	1	1	1
s. Magnetic amplifiers	1	1	1	1
31. Operating principles of amplitude, frequency, phase, and pulse modulation	1	1	1	1
32. Application and operating principles of:				
a. Wire and coaxial transmission lines	1	1	1	1
b. Wave guides	1	1	-	-
c. T/R tubes	1	1	-	-
d. AT/R tubes	1	1	-	-
e. Klystrons	1	1	1	-
f. Magnetrons	1	1	-	-
g. Crystal mixers	1	1	1	1
h. Magnetic amplifiers	1	1	1	1
33. Function and operating principles of gas-filled electron and cathode ray tubes	1	1	1	1

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
202 MAINTENANCE AND/OR REPAIR—Continued				
34. Methods of making RF power measurements on:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
35. Methods of coupling: Transformer, impedance, capacitance, resistive, and direct	1	1	1	1
36. Functions and applications of servomechanisms and synchros as applied to aviation electronic equipment	1	1	1	1
37. Method of making gain, phase, balancing, and zeroing adjustments to servo loops	1	1	1	1
38. Electrical characteristics of Hertz, Marconi, cone, sleeve, plate, slot, and dipole antennas; operating principles of dish reflectors and associated RF feeds and of parasitic reflectors and directors	C	C	C	C
39. Factors causing and methods of suppressing or eliminating radio noise interference	C	C	C	C
40. Cause and/or effect of induction field, radiation field, sky wave, ground wave, ground-reflected wave, ionospheric reflecting layers, skip distances, and maximum usable frequency	C	C	C	C
41. Methods of measuring field strength of radio waves	C	C	C	C
42. Effects of various combinations of beam widths, pulse length, pulse repetition frequency, and power output relative to performance and applications of radar equipment	C	C	-	-
43. Effects of environmental conditions upon operation of electronic and electrical equipment, and special maintenance techniques involved in equipments to be operated at extremes of altitude, temperature, and humidity	C	C	C	C
203 ADMINISTRATIVE AND/OR CLERICAL				
1. Types of forms and records used in maintenance and repair of:				
a. Aviation radar equipment	3	3	-	-
b. Aviation ASW equipment	3	-	3	-
c. Aviation communication and navigation equipment	3	-	-	3
2. Types of information found in aviation electronic technical and maintenance publications	3	3	3	3
3. Types of entries made in electronic portion of Standard Aircraft Inventory Log; types of information recorded in reports of equipment failure	2	2	2	2
4. Types of information found in electronic material bulletins and changes	2	2	2	2
5. Purpose and type of information contained in section "R" allowance list of aviation electronic material	2	2	2	2

Qualifications for Advancement in Rating	Applicable Rates			
	AT	ATR	ATS	ATN
203 ADMINISTRATIVE AND/OR CLERICAL--Continued				
6. Procedure for obtaining replacement parts, tools, test equipment, and materials for use within the shop for:				
a. Aviation radar equipment	1	1	-	-
b. Aviation ASW equipment	1	-	1	-
c. Aviation communication and navigation equipment	1	-	-	1
7. Types of information found in aviation circular letters, aircraft bulletins, and aircraft service changes	1	1	1	1
8. Application of allowance lists in determining spare parts, tools, and supplies authorized for own activity	1	1	1	1
9. Procedure for obtaining replacement parts, materials, authorized tools, and test equipment for the shop, and for returning defective equipment to supply system for processing to overhaul and repair facilities	C	C	C	C
10. Procedures for survey of accountable material	C	C	C	C

300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER

Aviation Electronics Technicians advance to Warrant Aviation Electronics Technician and/or to Limited Duty Officer, Aviation Electronics.

MILITARY REQUIREMENTS

Scope

Military requirements are those generally applicable qualifications which all enlisted personnel are expected to demonstrate as a minimum for advancement to specific pay grades. They are applicable to all personnel at the specified pay grade except where indicated for men or women only.

For advancement, enlisted personnel in any pay grade need to demonstrate proficiency in the qualifications specified for the next higher pay grade and should maintain, and may be required to demonstrate, qualification for all lower pay grades.

Knowledges essential to performance of the practical factors, as well as those essential to the required examination subjects, will be subject to examination for advancement.

100 PRACTICAL FACTORS

101 OPERATIONAL

		Applicable Pay Grade
1.	Enter water feet first from height of 5 feet and swim 50 yards; float, scull, and tread water	E-2
2.	Demonstrate techniques for preparing and using clothing and buoyant objects for staying afloat	E-2
3.	Demonstrate how to put on and use inherently buoyant and CO_2-inflatable life jackets	E-2
4.	Demonstrate how to control arterial and venous bleeding by compress, finger pressure and tourniquet	E-2
5.	Prepare and apply an improvised splint	E-2
6.	Administer artificial respiration by the back-pressure arm-lift method and back-pressure hip-lift method	E-2
7.	Transport an injured person by: a. Fireman's lift b. Tied-hands crawl.	E-2
8.	Tie a bowline, becket bend, round turn and two half hitches, and square knot. (Men only.)	E-2
9.	Locate an object by relative bearing and position angle measured in degrees. (Men only.)	E-2
10.	Demonstrate ability to use ABC warfare protective equipment such as masks and clothing	E-2
11.	Identify standard markers used to denote ABC warfare contamination	E-2
12.	Adapt regular issue clothing for atomic and biological protection	E-2
13.	Describe early symptoms of contamination of personnel by chemical warfare agents	E-3
14.	Apply a battle dressing	E-3
15.	Demonstrate how to apply immediate treatment for shock	E-3
16.	Demonstrate techniques of swimming through oil, flames, and debris	E-3
17.	Pronounce numbers and phonetic alphabet	E-3
18.	Break out, man, test, and secure a sound-powered phone head set. (Men only.)	E-3
19.	Demonstrate how to extinguish class A, B, and C fires. (Men only.)	E-3
20.	Demonstrate how to use: (Men only.) a. Portable CO_2 extinguishers. b. Hoses, nozzles, and adaptors. c. Safety lines and signals.	E-4

102 MAINTENANCE AND/OR REPAIR. (Men only.)

1.	Prepare aluminum, steel, and wood surfaces for painting	E-3

102 MAINTENANCE AND/OR REPAIR.

(Men only.)--Continued

	Applicable Pay Grade
2. Paint aluminum, steel, and wood surfaces, using standard Navy techniques	E-3
3. Clean and stow paint brushes	E-3
4. Field-strip, clean, and assemble the service rifle	E-3
5. Field-strip, clean, and assemble the service pistol	E-4

103 ADMINISTRATIVE AND/OR CLERICAL

1. Prepare an indoctrination schedule for a new recruit reporting for duty	E-5
2. Select and organize appropriate subject matter and instruct by showing (demonstration) method	E-5
3. Prepare a standard Navy letter	E-5
4. Prepare a detailed work assignment for men in your division	E-6
5. Teach a group, observing the following steps in developing the lesson:	E-6
a. Setting the objectives.	
b. Presenting the subject matter.	
c. Providing trainee application through practical work and drill.	
d. Summarizing key points.	
e. Testing trainee achievement.	
6. Prepare and administer a written test which includes the following types of questions:	E-6
a. Essay.	
b. Multiple choice.	
c. True-false.	
d. Completion.	
7. Use the following training aids and devices:	E-6
a. Training film, slides, and transparencies.	
b. Charts, posters.	
c. Models and mock-ups.	
d. Demonstrators and trainers.	
8. Prepare a preventive maintenance schedule for an item of machinery or equipment in your division, considering possible changes to ship employment schedule	E-7
9. Demonstrate ability to conduct instruction by each of the following methods, using subject matter appropriate to each method:	E-7
a. Telling (lecture).	
b. Questions and discussion.	
c. Drill and practical work.	
d. Written study materials.	
10. Plan and supervise on-the-job training program based on:	E-7
a. Level of trainees' knowledge and skill.	
b. Degree of skill to be developed.	
c. Available equipment and training aids.	
d. Qualifications for Advancement in Rating, NavPers 18068 (Revised).	

104 MILITARY CONDUCT

1. Execute individual positions and facings used in close-order drill, with and without arms. (Men only.)	E-2
2. Execute individual positions and facings, without arms. (Women only.)	E-2
3. Fire the service rifle, observing safety precautions. (Men only.)	E-2

104. MILITARY CONDUCT--Continued — Applicable Pay Grade

4. Relieve a watch, armed with rifle. (Men only.) E-2
5. Stand sentry watch, observing general orders. (Men only.) E-2
6. Stand a security watch. (Women only.). E-2
7. Command a squad in close-order drill E-4
8. Fire service pistol, observing safety precautions. (Men only.) E-4
9. Relieve a watch, armed with pistol. (Men only.) . . . E-4

200 EXAMINATION SUBJECTS

201 OPERATIONAL

1. Procedures and safety precautions involved in performing tasks appropriate to the applicable pay grades under 100 Practical Factors.
2. Individual action and precautions to be taken when exposed to atomic, biological, and chemical warfare attack ashore or afloat E-2
3. Use and care of inherently buoyant and CO_2-inflatable life preservers. (Men only.) E-2
4. Purpose and limitations of first aid E-2
5. Symptoms of and first-aid treatment for simple and compound fractures E-2
6. Procedures to be followed in removing clothing at personnel decontamination stations E-2
7. Rules of personal hygiene in relation to the following: E-2
    - a. Body.
    - b. Clothing.
    - c. Bedding.
    - d. Close living quarters.
    - e. Dangers of self-treatment.
8. Nomenclature of superstructure, decks, and parts of hull E-2
9. Numbering system for decks and lettering and numbering system for compartments. E-2
10. Main purpose of following knots: (Men only.) E-2
    - a. Bowline.
    - b. Becket bend.
    - c. Round turn and two half hitches.
    - d. Square knot.
11. Safety precautions to be observed in handling service rifle. (Men only.). E-2
12. Symptoms of and immediate treatment for shock . . . E-3
13. Occasions and precautions for administering a morphine syrette E-3
14. Classification of burns and symptoms of and first-aid treatment for each E-3
15. Preparation for abandoning ship; best ways of going over the side; and type of clothing to be taken in abandoning ship in hot or cold climate. (Men only.) . E-3
16. Use, care, and stowage of the following life float equipment: (Men only.) E-3
    - a. Signal mirror.
    - b. Day and night distress signal.
    - c. Dye marker.
    - d. First-aid kit.
    - e. Rations.
    - f. Tarpaulin.
17. Major types of and designating symbols for U. S. naval ships E-3

201 OPERATIONAL--Continued	Applicable Pay Grade
18. Major classes of and designating symbols for U. S. naval aircraft	E-3
19. Material conditions of readiness of a ship. Meanings of W, X, Y, Z damage control markings. (Men only.)	E-3
20. Types of guns installed aboard United States cruisers, destroyers, and naval aircraft	E-3
21. General purposes of the following types of naval ordnance:	E-3
a. Bombs.	
b. Rockets.	
c. Projectiles.	
d. Guided missiles.	
e. Depth charges.	
f. Torpedoes.	
g. Mines.	
h. Pyrotechnics.	
22. Three classes of fires and their:	E-3
a. Causes.	
b. Prevention.	
c. Methods of handling.	
23. Hazards of fire-produced smokes and fumes	E-3
24. General safety precautions involved in working with or in vicinity of: (Men only.)	E-3
a. Tank or closed compartment.	
b. Electrical and electronic equipment.	
c. Machinery and power tools.	
d. Fuels, paints, and solvents.	
e. Ammunition.	
f. Compressed gases.	
g. Life lines, ladders, and scaffolding.	
h. Heavy weights and moving equipment.	
25. Safety precautions when working aloft or over the side. (Men only.)	E-3
26. Safety precautions when embarked in small boats.	E-3
27. Early symptoms of exposure to chemical warfare agents	E-3
28. Sound signals for steam vessels during reduced visibility under way and at anchor. (Men only.)	E-4
29. Ship distress and break-down signals according to International Rules. (Men only.)	E-4
30. Whistle signals for meeting, crossing, and passing according to Inland Rules.	E-4
31. United States buoyage system for marking channels and obstructions.	E-4
32. Use of desalting kit and solar distilling equipment for obtaining drinking water; methods of catching and stowing rain water. (Men only.)	E-4
33. Safety precautions to be observed in handling service pistol. (Men only.)	E-4
34. Identify the semaphore positions for numbers and letters of the alphabet	E-5
35. Identify the International Morse Code for numbers and letters of the alphabet	E-5
36. Methods of decontaminating chemical, biological, and radioactive painted and unpainted surfaces. (Men only.)	E-7
37. Purpose and use of ABC warfare detector devices such as survey meters, dosimeters, and sampling kits.	E-7

202 MAINTENANCE AND/OR REPAIR. (Men only.)

1. Methods of preparing wood, steel, and aluminum surfaces for painting	E-3

202 MAINTENANCE AND/OR REPAIR. (Men Only.)--Continued

Applicable Pay Grade

2. Uses of zinc chromate and red lead primers; exterior and interior paints E-3
3. Methods of cleaning and stowing paint brushes. E-3

203 ADMINISTRATIVE AND/OR CLERICAL

1. How and when to place personnel on report. E-4
2. Meaning and application of the following leadership principles: E-4
   a. Knowing the job to be done.
   b. Exhibiting and instilling pride in high standards of work.
   c. Seeking additional responsibility.
   d. Knowing your men and recognizing individual differences.
   e. Possessing sense of responsibility.
   f. Delegating authority but not responsibility.
   g. Keeping men informed.
   h. Being forehanded.
   i. Commanding and leading.
3. Correct form for a standard Navy letter. E-5
4. The purpose and relationship of the following in teaching a lesson: E-6
   a. Preparation.
   b. Presentation.
   c. Application.
   d. Test.
   e. Summary.
5. Standards to follow and errors to avoid in evaluating personnel for performance of duty marks E-6
6. Responsibilities of petty officers in on-the-job training programs regarding: E-6
   a. Training of individuals.
   b. Team training.
   c. Departmental training.
7. How and when to praise, censure, and warn. E-7
8. Importance and effect of the following in planning and conducting instruction: E-7
   a. Objectives of the lesson.
   b. Characteristics of the subject or skill to be learned.
   c. Degrees of the skill required of trainees.
   d. Conditions, including time available, under which training must be conducted.
   e. Available equipment and training aids.
   f. Instructor-trainee relationships.

204 MILITARY CONDUCT

1. Eleven general orders for a sentry. (Men only.) . . . E-2
2. When and to whom the individual hand and rifle salutes are rendered E-2
3. Military courtesies required of enlisted personnel in the following situations: E-2
   a. During colors.
   b. Boarding or leaving a naval vessel.
   c. Crossing or being in the vicinity of the quarter deck.
   d. When in military or civilian dress and the national ensign passes or national anthem is played.
   e. When passing, meeting, addressing, introducing, replying to, walking with, or riding with any commissioned officer attached to or serving with U. S. armed services.

204 MILITARY CONDUCT--Continued

	Applicable Pay Grade
4. Authority of and services rendered by military police patrols	E-2
5. Identify officer grade insignia and corps devices of the U. S. Navy	E-2
6. Identify rates in pay grades E-1, E-2, and E-3 by sleeve insignia	E-2
7. Identify rates of petty officers by sleeve insignia	E-2
8. Regulations for the correct wearing, markings, and exchanging of U. S. Navy enlisted uniforms for other than pay grade E-7	E-2
9. Principal occupational duties of general service ratings	E-2
10. Five types of discharge and reasons for each	E-2
11. Requirements and advantages of an honorable discharge	E-2
12. Identify the ribbons for the following medals:	E-3
a. Medal of Honor.	
b. Navy Cross.	
c. Good Conduct Medal.	
13. Names of parts of the Naval Establishment and the mission of each	E-3
14. Names, abbreviations, and broad responsibilities of the various bureaus of the Navy Department	E-3
15. Standard ship organization and the general responsibilities of each department	E-3
16. Purpose of watch, quarter, and station bill	E-3
17. Purpose of military discipline and punishment	E-3
18. Contents of the General Article (No. 134) of the Uniform Code of Military Justice and definition and significance of the following offenses:	E-3
a. Desertion.	
b. AWOL.	
c. Misuse of United States property.	
d. Insubordination.	
e. Fraudulent enlistment.	
f. Drunkenness or reckless driving.	
19. Types of courts martial and maximum punishments each may award	E-3
20. Punishments which the commanding officer may award	E-3
21. Meaning of basic pay, basic allowance for subsistence and quarters, and commuted rations	E-3
22. Types of hazardous duty entitling personnel to incentive pay. (Men only.)	E-3
23. Meaning and examples of rate and rating	E-3
24. General requirements for eligibility for advancement in rate or rating	E-3
25. Purpose and effect of performance of duty marks	E-3
26. Purpose of the following:	E-3
a. Service, fleet, and functional schools.	
b. Navy training courses.	
c. Enlisted correspondence courses.	
d. USAFI correspondence courses.	
e. USAFI self-study courses.	
f. Accreditation service of the information and education program.	
27. Opportunities for acquiring a naval commission in the following programs:	E-3
a. Officer Candidate School. (Men only.)	
b. Naval Reserve Officers Training Corps. (Men only.)	
c. Naval Aviation Cadet Program. (Men only.)	
d. Naval Academy. (Men only.)	
e. Reserve Officer Candidate. (Men only.)	

204 MILITARY CONDUCT--Continued	Applicable Pay Grade
27. Opportunities for acquiring a naval commission in the following programs--Continued	
f. Reserve Officer Candidate (W). (Women only.)	
g. Officer Indoctrination (W). (Women only.)	
h. Naval Preparatory School. (Men only.)	
28. Contents of the following sections of the enlisted service record:	E-3
a. Record of Emergency Data.	
b. Enlisted Classification Record.	
c. Navy Occupation and Training History.	
d. Marks.	
29. Purpose of primary and secondary NEC codes	E-3
30. Meaning of following terms:	E-3
a. Accrued leave.	
b. Earned leave.	
c. Emergency leave.	
d. Excess leave.	
e. Advance leave.	
31. Personal services available to enlisted men and their dependents, including Red Cross and Navy Relief	E-3
32. Correct method of submitting a request through official channels	E-3
33. Regulations concerning identification tags and identification cards	E-3
34. Meaning of the following security classifications:	E-3
a. Top Secret.	
b. Secret.	
c. Confidential.	
35. Current security regulations concerning personal correspondence and oral communications. (U.S. Navy Security Manual for Classified Matter)	E-3
36. Regulations concerning loss, compromise, and unauthorized disclosure of classified matter	E-4
37. Enlisted person's responsibilities in the following situations:	E-4
a. When ship and boat passing honors are rendered.	
b. When in the vicinity of a gun salute.	
38. Identify officer ranks and enlisted grades of other branches of U. S. armed services	E-4
39. General duties of the following:	E-4
a. Guard mail petty officer	
b. Section leader.	
c. Gangway petty officer. (Men only.)	
d. Master at arms.	
e. Police petty officer.	
40. General duties of military police patrols with respect to:	E-4
a. Apprehension of offenders.	
b. Contact with officers.	
c. Contact with civilians.	
41. Alarms and calls for fire and collision	E-4
42. General duties and authority with respect to civilians of a naval landing party in a distressed or disturbed area	E-5
43. Purpose and effect of the Chief and First Class Petty Officer Evaluation Sheet, NavPers 1339	E-6
44. Regulations for the correct wearing, marking, and exchanging of U. S. Navy enlisted uniforms of chief petty officers	E-7

INDEX

A-c/d-c generating system, 107-108
A-c generating system, 105-107
Active ECM equipment, 383-386
Advancement, qualifications for, 5-6
  emergency rating, 6
  examination subjects, 6
  general rating, 5
  Manual of Qualifications for Advancement in Rating, NavPers 18068, 5
  practical factors, 6
  service rating, 5
Advancement requirements:
  active duty, V
  inactive duty, IV
AEW system, 356
Airborne auxiliary power units, 114-115
Airborne radar. (See Radar, airborne.)
Airborne sonar. (See Sonar, airborne.)
Airborne sonobuoys. (See Sonobuoys.)
Aircraft electric power systems, 103-120
  auxiliary power units, 112-115
    airborne, 114
    Homelite, 113
    NC-5, 112-115
    NC-6, 113
    Waukesha, 113
  circuit protectors, 116-120
  deckedge, 115-116
  dynamotors, 129-130
  generating systems, 103-108
    a-c/d-c, 107-108
    alternating-current, 105-107
    direct-current, 104-105
  inverters, 125-128
  relays, 123-125
  storage batteries, 108-112
    lead-acid, 108-110
    nickel-cadmium, 110-112
  switches, 120-123
    maintenance, 123
    manual operated, 120-121
    mechanical operated, 121-123
Allowance lists, aeronautical, 25-26
  electronic accessories, 26
  electronics material, 26
  electron tubes, 26
  test equipment, 26
All-weather attack radar, 356-359
Alphabet, Greek, 432
Altimeters, radar, 361-364
Altitude delay, radar, 347
Amplifiers, magnetic. (See Magnetic amplifiers.)
Analog computers, 72-99
AN electrical connectors:
  moisture proofing (potting), 199-202
  service, inspection, and maintenance, 199
AN nomenclature system, 27-30
Anomaly:
  magnetic, 388
  strength, 394-395
  submarine, the, 393-396
Answers to quizzes, 437-440
Antennas, ECM, 372, 375-376
Antenna system, radar, 343
APN-70 loran receiver, 297-301
ARC-2, 232-236
ARC-27, 242-251
ARC-27A, 250-251
ARC-38, 236-242
ARN-14, 323-329
ARN-21, 329-332
ARR-41, 222-227
Artificial respiration, 13-15
Attack radar, all-weather, 356-359
Atomic structure of semiconductors, 33
ATR tube, 343
Auxiliary power unit (APU), 103, 112-115

Basic training courses:
  Basic Electricity, NavPers 10086, 4
  Basic Electronics, NavPers 10087, 4
  Basic Hand Tool Skills, NavPers 10085, 4
  Basic Machines, NavPers 10624, 4
  Blueprint Reading and Sketching, NavPers 10077-A, 4
  Mathematics, Vol. 1, NavPers 10069-B, 4
Batteries, storage, 108-112
Beacon receiver, sonobuoy, 424
Beacons, radar, 360-361
Billets, types and locations:
  aircraft carrier, 3
  Naval Air Station, 2
  squadron, 2
  training, 3
Binary numbers and numbering system, 68-69
Bonding, 211-212
Bridge, magnetometer, 391-393
Burns, thermal, treatment of, 15

Cables and terminals:
  cables, 202-203
  clamps, cable, 206-207
  lacing and tying, 207-211
  terminals, 203-206
Calculus, computer:
  differentiation, 92-95
  integration, 95-97
Cathode-ray tube, 143-146
  handling, 10-11
Cavity wavemeters, 165-166
Changes:
  aircraft service, 19
  electronic material, 18-19
Checks, maintenance. (See inspections.)
Circuit breakers, 118-120

Circuit protectors, 116-120
  circuit breakers, 118-120
  current limiters, 118
  fuses, 116-118
Communication equipment, 219-251, 254-269
  ARC-2, 232-236
  ARC-27, 242-251
  ARC-27A, 250-251
  ARC-38, 236-242
  ARR-41, 222-227
  ART-13, 227-232
  intercommunication, 219-222
    AIC-15, 220-222
  single sideband, 254-269
    demodulation, 260-261
    mechanical filters, 262-265
    sidebands, 257-259
    transducer, 262-265
Composite signal (TV), 284-289
Computer, navigational, 366
Computers:
  analog, principles of, 72-73
  classification, 67
  digital, principles of, 68
  general design requirements, 69
  input unit, 70
  logical unit, 70
  memory unit, 70
  output unit, 70
  types, 67-68
Construction of circuits:
  book, 194
  modular, 193-194
  potted units, 194
  printed, 190-193
Contents, table of, VII
Countermeasures, electronic. (See Electronic Countermeasures.)
Courses, basic training, 4
Covalent bonds, 33
Crimping tools, 205
Crystal structure of semiconductors, 33-34
Current flow, transistors:
  hole and electron flow, 34-35
Current limiters, 118

D-c generating system, 104-105
Deckedge power, 115-116
Demodulation, 260-261
Detection equipment, magnetic airborne. (See Magnetic airborne detection equipment.)
Detonators, electric, 9
Differentiation, computer calculus:
  electromechanical, 94
  electronic, 93-94
  mechanical, 95
Digest—U. S. Naval Aviation Electronics, 19-20
Digital computers, 68-72
Dipping sonar, 415
Direction finders, ECM, 372, 379-382
Distance measuring equipment, 318-320
Division by computers, 83-85
Doppler:
  effect, 364-365
  radar, 408-412
Duplexer, 343
Duties and responsibilities:
  military, 1
  professional, 1
Dynamotor, 129-130

Echo boxes, 168-171
Electric power systems, aircraft. (See Aircraft electric power systems.)
Electric shock:
  artificial respiration, 13-15
  body resistance, 13
Electrical and electronics terms, 427-432
Electrical summation by computers, 73-76
Electronic countermeasures (ECM):
  active ECM equipment, 383-386
    antijamming circuits, 385
    automatic jamming equipment, 384-385
    jamming transmitters, 383-384
    nonelectric jamming, 385-386
  equipment, 371-372
  passive ECM equipment, 373
    direction finders, 379-382
    indicator patterns, 379-382
    pattern, 377
    pulse analyzer, 377-379
    search antennas, 375-376
    search receivers, 373, 375-376
    wave traps, 376
  signal characteristics, 372
    beam width, 373
    carrier frequency, 372
    pulse repetition frequency, 372-373
    pulse width, 373
    scan, 373
  test equipment, 386
Electronics:
  division, 84-85
  failure report, 21-23
  maintenance, safety in. (See Safety precautions.)
  material, changes and bulletins, 18-19
  multiplication, 76-79
Electronics and electrical terms, 427-432
Electromechanical:
  division, 83-84
  multiplication, 79
  summation, 76
Electrostatic deflection in CRT, 145-146
Equation arrangement for computers, 70-71
Equipment for ECM:
  antennas, 372
  direction finders, 372
  panoramic adapters, 372
  pulse analyzers, 372
  recorders, 372
  search receiver, 371-372
Exponents, laws of, 436

Failure, Unsatisfactory or Removal Report (FUR), 23
Formulas, electronics and electrical, 433-435
First aid. (See Safety precautions.)
Frequency bands, table, 219
Fuses, 116-118

Generating systems:
  a-c/d-c, 107-108
  alternating-current, 105-107
  direct-current, 104-105
Germanium, semiconductor, 33
Greek alphabet, 432

Handbooks, BuAer, 17-18
  operating instructions, 18
  service instructions, 18
Heat shunts, soldering, 194-195
Homélite auxiliary power unit, 113
Hydrophones, 413

Iconoscope, 279
IFF systems, 359-360
Image Orthicon, 279-280
Indicator, radar, 344
Infrared, 332-335
Input unit, computer, 70
Inspections, electronic maintenance:
  acceptance and transfer, 185
  daily and preflight, 183-184
  inventory, 185-186
  periodic:
    calendar intermediate, 185
    calendar major, 185
    crew leader, 185
    intermediate, 184
Integration, computer calculus:
  mechanical, 96-97
  principles of, 95-96
Instructions and notices, 20
Instrument landing system, 316-318
Intercommunication equipment, 219-222
Interlaced scanning (TV), 282-284
Inventory logs, standard, 23-24
Inverters:
  operation, 128-129
  filters, 128
  generator, 128
  motor, 125-127
  motor armature, 127
  speed governor, 127-128
Ions, 33

Jamming transmitters, 383-384
Junction transistors, 36-37

Laws of exponents, 436
Lead-acid batteries, 108-110
Logarithms, computer, 90-91
Logical unit, computer, 70
Loran, 292-301

MAD equipment, 388-401
  ASQ-8, 397-399
  ASQ-10, 399-401
Magnetic airborne detection:
  magnetic noise and compensation, 396-397
    compensation, 396-397
    noise sources, 396
  principles of magnetic detection, 388-393
    effect of external field on magnetometer, 390
    magnetic anomaly, 388
Magnetic airborne detection--Continued:
  principles of magnetic detection--Continued:
    magnetometer bridge, 391-393
    magnetometer orientation, 391
    saturable core magnetometers, 388-390
  submarine anomaly, 393-396
    anomaly strength, 394-395
    orientor operation, 395-396
    problem of detection, 393-394
  typical MAD equipments, 397-401
    ASQ-8 MAD set, 397-399
    ASQ-10 MAD set, 399-401
Magnetic amplifiers:
  advantages and disadvantages, 62-64
  amplifiers with full-wave rectification, 60-61
  amplifier with half-wave rectifier, 56-58
  applications, 62
  basic circuits, 55-56
    simple amplifier, 55-56
    three-legged magnetic core, 56
  external feedback, 61-62
  principles of operation, 52-53
  saturable reactor cores, 53-55
    toridal windings, 54
  self-saturating amplifier, 58
    bias for flux reset, 60
    effects of hysteresis, 58-60
Magnetometers, saturable core, 388-390
  effect of external field, 390
    saturation, 390
    varying field direction, 390
  orientation, 391
    aircraft maneuver error, 391
    automatic, 391
Magnetostriction, 412-413
Maintenance, general:
  bearings, rotating equipment, 215
  checks, (See inspections.)
  commutator, brush, and slipring, 214-215
  publications, (See Publications.)
  relays, 125
  sonar, 420
  switches, 123
Manual of Qualifications for Advancement in Rating, NavPers 18068, 5
Material reliability reports, 20-21
Mechanical:
  division, 85
  filter, 262-265
  multiplication and multipliers,
    cam, 82-83
    rack, 80-81
    screw, 79-80
    sector, 81-82
Memory unit, computer, 70
Micromatch (SWR meter), 154-156
Military requirements, 452-458
  duties, 1
  examination subjects, 454-458
  practical factors, 452-454
Modular construction, 193-194
Modulation, 256-257
Modulator, radar, 343
Multiplication by computers, 76-83

Naval Aeronautic Publications Index:
  part 1, 17
  part 2, 17
  part 3, 17-18
Navigational computer, 366
  airspeed channel, 366
  distance channel, 368
  ground speed, 368
  ground track channel, 368
  heading channel, 366
  wind channel, 368
Navigation equipment, 292-332
  automatic direction finders, 301-313
    antennas, 302
    ARA-25, 311-313
    ARN-41A, 302-311
    wave propagation, 304-306
  distance measuring equipment, 320-323
    ARN-21, 329-332
  instrument landing system, 316-318
  loran, 292-301
    APN-70 receiver, 297-301
  omnidirectional range (VOR), 318-320
    ARN-14, 323-329
  radio markers, 314-315
  radio ranges, 314
  visual-aural range (VAR), 315-316
NC-5 auxiliary power unit, 112-113
NC-6 auxiliary power unit, 113
Nickel-cadmium batteries, 110-112
Nomenclature system, AN, 27-30
Nonelectronic jamming, 385-386
Notices and instructions, 20

Omnidirectional receiver (ARN-14), 323-329
Open center operation, radar, 347
Oscilloscope, 143-149
  fundamental elements, 146-147
Output unit, computer, 70

Panoramic adapters, 372-376
Passive ECM equipment, 379-382
Patterns:
  direction finder, 380
  panoramic adapter, 377
Percentage of modulation, 256-257
Piezoelectric transducer, 413
Power:
  absorption cones, 167-168
  measurement (with wattmeter), 150-152
  systems, electric, aircraft. (See Aircraft power systems.)
Power-gain formula, transistor, 40
Powers and Roots, computer, 85-87
Point-contact transistors, 37
Potting (See AN Electrical connectors: moisture proofing, 199-202)
Preface, 111
Procurement of equipment:
  aeronautical allowance lists, 25-26
  shop requisitions, 26
Professional:
  duties, 1
  requirements, 441
    examination subjects, 446-451
    practical factors, 442-446
Printed circuits, 190-193
Publications, maintenance:
  aircraft service changes, 19
  BuAer bulletins, 19
  BuAer handbooks, 17-18
  BuAer instructions, 19
  Digest, U. S. Naval Aviation Electronics, 19-20
  electronic material bulletins, 19
  electronic material changes, 18-19
  Naval Aeronautic Publications Index, 17-18
  technical notes, 19
  technical orders, 19
Pulse:
  analyzers, 372, 377-379
  generator, 171-172

Qualifications for advancement in rating, 5-6, 441-458
  military requirements, 452-458
  professional requirements, 447-451
Quizzes, answers to, 437-440

Radar, airborne, 339-368
  all-weather attack, 356-359
    acquisition scan, 358
    gun aim presentation, 358-359
    intercept operation, 357
    search scan, 356
  altimeters, 361-364
  doppler, 364-365
  IFF system, 359-360
  radar beacons, 360-361
  search, 340
    components of system, 342-344
    PPI presentation, 342
    range measurement, 340-342
    typical set, AN/APS-33, 344-356
  special attachments, 365
    ground position indicators, 365-366
    navigational computer, 366-368
Radiation symbol, 12
Radioactive tubes, safety with:
  disposal, 11-12
  first aid, 12
  handling, 11
  identification, 12
Radio:
  markers, 314-315
  ranges, 314
  wave travel, 304-306
Range recorder, sonar, 417
Reading list, VI
Receiver:
  ECM, 373, 375, 376
  radar, 344
Recorders, ECM, 372
Records and reports:
  aircraft inspection check sheets, 24
  Electronic Failure Report (EFR), 21-23
  Failure, Unsatisfactory, or Removal Report (FUR), 23
  maintenance and repair records, 24-25
    record of electronic material changes, 24
    work log, 24-25

Records and reports--Continued:
  material reliability, 20-21
  standard inventory logs, 23-24
Relative and true bearing operation, radar, 346
Relays, 123-125
Repairing printed circuits, 192-193
Reports and records. (See Records and reports.)
Rope, ECM, 385

Safety precautions:
  aircraft, 8-9
  cathode-ray tubes, 10-11
  electric detonators, 9
  electric shock, 13
    artificial respiration, 13-15
    body resistance, 13
  electrical fires, 10
  energized circuits, 10
  general, 9
  high-voltage, 9
  power tools, 13
  radioactive tubes, 11
    disposal, 11-12
    first aid procedure, 12
    handling, 11
    identification, 12
  selenium rectifiers, 11
  soldering irons, 12-13
  thermal burns, 15
Saturable core magnetometers, 388-390
Saturable reactor cores, 53-55
Safety wiring, 212-214
Scale factor, computer, 72
Search radar, airborne, typical set, 340-356
  control unit, 347-349
  description and operation, 345
  duplexer, 353
  electrical characteristics, 349
  indicator assembly, 354
  presentation control, 352
  radiation system, 351
  reception of reflected signals, 351-352
  theory of operation, 349
  transmitted signal, 350
Sector scan presentation, radar, 346
Selenium rectifiers, safety with, 11
Semiconductors, 32-34
Serrated vertical pulse (TV), 286
SG-85/URM-25D RF signal generator, 163-164
Shock, electric. (See Electric shock.)
Signal generators, 161-165, 171-172
Silicon, semiconductor, 33
Single sideband, 254-269
Soldering, 12-13, 194-199
  irons, safety with, 12-13
  semiconductors, 194-195
Solution of linear problems, computer:
  division, 83-85
  multiplication, 76-83
  summation, 73-76
Sonar, airborne, 403-420
  doppler effect, 408-412
  factors affecting sound beam, 404-408
    absorption, 404

Sonar, airborne--Continued:
  factors affecting sound beam--Continued:
    depth and temperature, 407-408
    reflection, 404-405
    refraction, 405-406
    reverberations, 405
    scattering, 404
    speed, 406-407
    spreading or divergence, 405
  hydrophones, 413
  maintenance, 420
  sonar systems, 414-415
  transducer, 412-413
    construction, 413
    magnetostriction principle, 412-413
    piezoelectric, principle, 413
  typical set, 415
Sonobuoys, 420-425
  beacon receiver, 424
  general description, 420-422
  pattern, 424
  testing, 424-425
  theory of operation, 422
Sound beam, sonar, 404-408
Sound, intercarrier (TV), 288-289
  split-sound, 288-289
Squaring cam, 86
Study guide, VIII
Submarine, anomaly, 393-396
Summation by computers, 73-76
Switches:
  maintenance, 123
  manually operated, 120-121
  mechanically operated, 121-123
Symbol, radiation, 12
Symbols, transistor:
  diode, 38
  NPN, PNP, NPN tetrode, 45
  PNP, 40, 45
Synchronizer, radar, 342

Tape recorders, 270-275
  UHN-6, 274-275
Target discrimination, radar, 347
Television, 276-288
  Iconoscope, 279
  Image Orthicon, 279-280
  interlaced scanning, 282-284
  signal, 284-289
    serrated vertical pulse, 286
  sound systems, 288-289
    intercarrier, 288-289
    split-sound, 288-289
Terminals. (See cables and terminals.)
Terms, electronics and electrical, 427-432
Test Equipment:
  combination test equipment, UPM-32, 179-180
  crystal testing, 173-175
  echo boxes, 168-171
  field strength meters, 156-157
  frequency meters, 157
  multimeter TS-352A/U, 134-135
  oscilloscope, 143-149
    CRT, 143-144
    deflection plates, 144-145

Test Equipment—Continued:
  oscilloscope—Continued:
    sweep time, 146
  power absorption cones, 167-168
  range calibrator set, UPM-11, 176-177
  RF wattmeter, 149-153
  signal generators, 161-165, 171-172
  spectrum analyzers, 176-179
  standing wave ratio meter, 153-156
  tube tester, 138-143
  vacuum tube voltmeter, 136-138
  wavemeters, 165-167
Tetravalent, 33
Tilt stabilization, radar, 346
Toridal windings, 54
Towed sonar, 416, 418
TR tube, 343
Training course, scope and purpose, 3
Transducer:
  sonar, 412-413
  SSB, 262-265
Transistors
  applications, 48-51
    amplifiers, 49-50
    oscillators, 48-49
    switching, 51
  basic circuits, 45-48
    grounded-base, 45
    grounded-collector, 48
    grounded-emitter, 45-48
  characteristics, 43-45
    characteristics, 45, 46
    cutoff frequency, 44
    frequency response, 43
    noise, 44
    power handling capabilities, 44
    temperature considerations, 44
  diode applications, 38
  diode symbols, 38
  hole and electron flow, 34-35
  N-type semiconductor material, 35
  PN junctions, 36-37
  P-type semiconductor material, 35
  point-contact, 37
  semiconductors, 32-34
    atomic structure, 33
    crystal structure, 33-34
  symbols, 38, 40, 45
  transistor theory, 38-43
    intrinsic barrier, 43
    NPN junction, 38-40
Transistors—Continued:
  transistor theory—Continued:
    PNP junction, 40-41
    point-contact, 41
    power gain (point-contact), 42
    power gain junction, 40
    tetrode, 42
    voltage gain (point-contact), 41
    voltage gain (junction), 39
Transmitters:
  ART-13, 227-232
  jamming, ECM, 383-384
  radar, 343
Transponder, 360
Trigonometric functions, computer:
  electromechanical, 87-90
  mechanical, 90
Troubleshooting:
  aircraft procedures, 186
  bench procedures:
    operational check, 190
    parts replacement, 188-190
    resistance checks, 188
    signal training, 187
    visual inspection, 186-187
    voltage checks, 187-188
TS-323/UR frequency meter, 159-161
TS-352 A/U multimeter, 134-135
TS-505 vacuum tube voltmeter, 136-138
TS-622 signal generator, 171-172
TV-7/U tube tester, 138-143

UHN-6 tape recorder, 274-275
UPM-11 range calibrator, 176-179
UPM-32, 179-180
URM-25D RF signal generator, 163-164
USM-24 oscilloscope, 147-149

Valence electrons, 33
Video generator, 171-172
Visual-aural range (VAR), 315-316
Voltage gain formula, transistors, 39

Wattmeter, 149-153
  model 670, 150
Wavemeters, 165-167
Waukesha auxiliary power unit, 113
Window, ECM, 385
Wiring. (See Cables and terminals.)
Work logs, 24

UNIVERSITY OF ILLINOIS-URBANA
629.1354UN3AE1959 C001
AVIATION ELECTRONICS TECHNICIAN 3 & 2$WA
3 0112 008596642

Google